DOCUMENT RESUME

ED 053 925 SE 011 320

AUTHOR	Wilson, James H.
TITLE	Two Over Mars, Mariner VI and Mariner VII February to August 1969.
INSTITUTION	California Inst. of Tech., Pasadena.
SPONS AGENCY	National Aeronautics and Space Administration, Washington, D.C.
REPORT NO	EP-90
PUB DATE	71
NOTE	46p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 ($0.50)
EDRS PRICE	EDRS Price MF-$0.65 HC-$3.29
DESCRIPTORS	*Aerospace Technology, *Astronomy, Resource Materials

ABSTRACT

This publication details the missions of Mariners 6 and 7 to the vicinity of Mars in the summer of 1969. Description is provided of the spacecraft, its preparation for flight, the 60 million mile journey, and the scientific results of the mission. There are numerous photographs including close-ups of the Martian surface. The content is narrative and technically valid but not burdened with detail. (Author/PR)

TWO OVER MARS

MARINER VI AND MARINER VII

TWO OVER MARS

MARINER VI AND MARINER VII
FEBRUARY TO AUGUST 1969

James H. Wilson

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JET PROPULSION LABORATORY/CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

Contents

Prepared Under Contract No. NAS7-100
National Aeronautics and Space Administration

This publication available for purchase as NASA EP-90 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.

☆U.S. GOVERNMENT PRINTING OFFICE: 1971 O—417-789

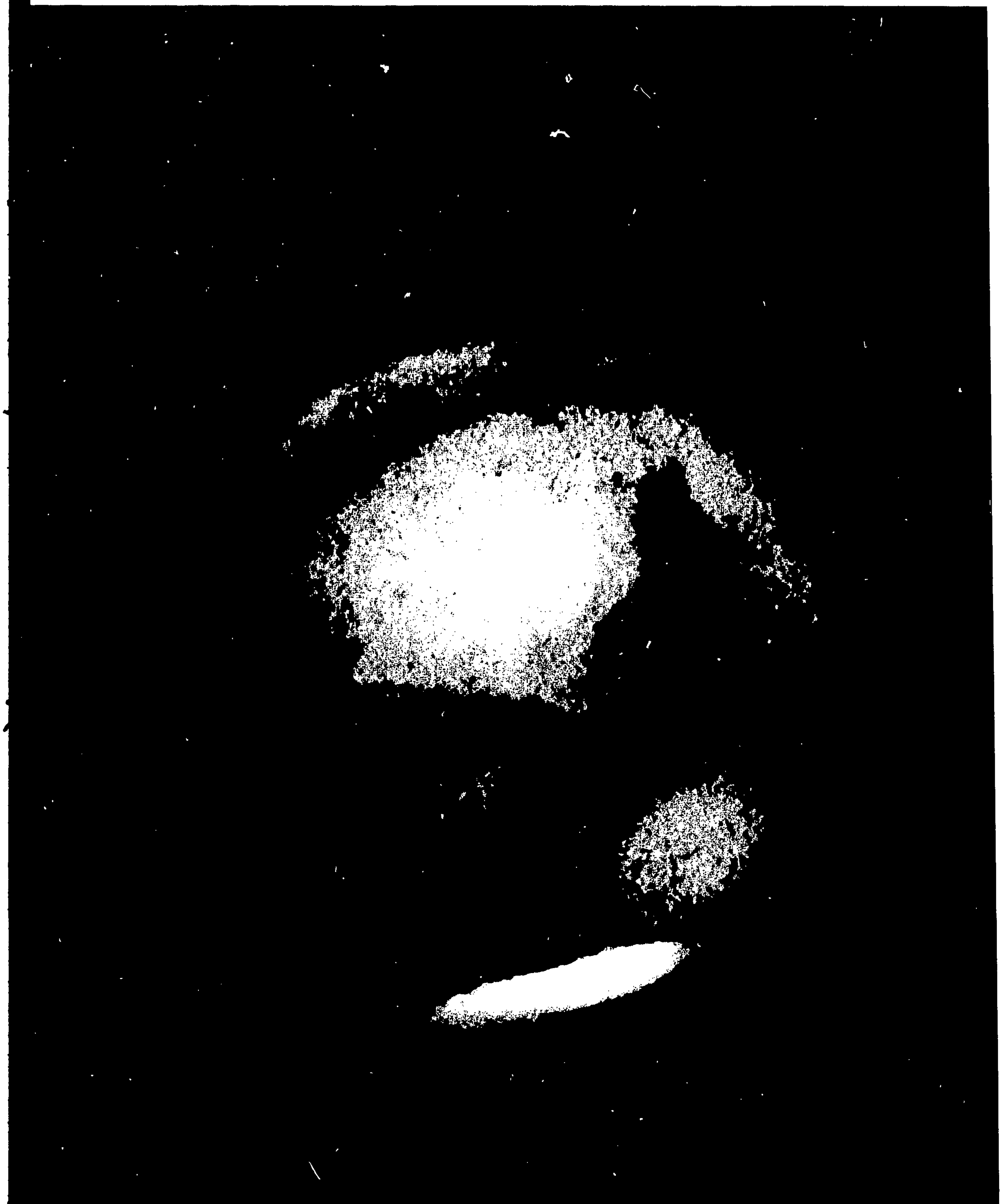
For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents

Preface

The Mariner Mars 1969 Project began at the end of 1965, while the results of the first mission from Earth to Mars were still being studied. It reached its peak in the summer of 1969, just after the first manned landing on the Moon. Surrounding and contemporary with the Project, the total space program evolved and matured. Mariner Mars 1969 itself turned a major corner in the exploration of Mars, the Mariner series, and the unmanned planetary program. As far as the near planets were concerned, the pioneering was over, and the detailed work had begun. The target was no longer simply Mars. Now a long and specific list of scientific questions was to be answered. Instruments were to be delivered to specific sites at particular times and pointed in prescribed directions.

The technical characteristics, engineering development, flight performance, and scientific results of Mariner Mars 1969 are described at length and in detail in a number of reports and publications, many of which are listed in the Bibliography. This document is intended to serve as an integrated introduction in narrative form, technically valid but not burdened with detail, to the Mariner Mars 1969 Mission and Project.

The effort was one of many carried out by and for the United States' National Aeronautics and Space Administration, which is generally responsible for flights, tests, development, and research in the fields suggested by its name. The Project was managed and conducted by the Caltech Jet Propulsion Laboratory, which was responsible for all previous Mariner projects as well as the Ranger and Surveyor lunar missions, several early Explorer and Pioneer flights, the deep-space tracking network, and an extensive research and development program sponsored by NASA.



Interlude

Sixty million miles away, on the warm, watery blue world called Earth, the month of August 1969 has begun. It is high summer on the wide brown continents of the northern hemisphere, while south of the equator spring is poised to begin. Much closer, on the rusty, dusty, battered planet Mars, summer is over in the northern hemisphere, and winter is waning to the South. The southern polar cap, at this time the most prominent large feature of the planet, has begun to shrink as the Sun's track moves South from its northernmost extension. In the thin, cold air, the frosty clouds blow away or dissolve. But above Mars, in space, there is no season, no weather, and little sense of time.

Earth-style, it is four years and a fortnight since the first ship of Earth coasted through these parts. On the Martian calendar, two years and 100 days have passed since the time of Mariner IV. The same spacecraft is about 225 million miles away, derelict and tumbling, sailing its gravity-governed course around the Sun. But its crew have never left Earth.

Still closer to Mars are other ships of Earth. Twin lineal descendants of the first Mariner, built in the same yards and launched from the same dock, they follow closely in its wake, as Leif Ericson followed Eric the Red across the North Atlantic. Their object is to build upon that first contact, to extend its scientific exploration both in scale and in kind, and to establish a basis for further investigation, particularly for a search for extraterrestrial life. Their crew also is far behind them, back on Earth. Scientists, engineers, and executives, technicians, secretaries, and craftsmen wait at the end of a long radio beam which takes more than five minutes to bring the word home from Mariner VI and Mariner VII. Thus, the mission in fact has brought not two, but more than two thousand over Mars. It is not machines that go out and explore, but people.

Now the first of the two new Mariner machines has finished its exploration of the fourth planet, conducted in two stages. As it fell toward Mars for two days, speeding up in the far-reaching gravitational pull, Mariner VI

Facing: The planet Mars observed by Mariner VII at a distance of 452,000 miles on August 4, 1969. Central dark features are Syrtis Major, at right, and Meridiani Sinus, projecting to left.

photographed the swelling globe, recording the pictures and transmitting each day's batch back to Earth. Then, at a range of 5000 miles, it began the comprehensive close-range survey.

Glass eyes wide, it gazed across the alien land. The big metallic head swung and nodded to take in the view, sweeping the horizon twice to be sure of the atmospheric profile. Then, as it crossed from day to night, the last picture was recorded, and the survey was left to the ultraviolet and infrared analyzers. A few moments after having passed across the night side, Mariner slipped into Earth occultation, and the radio signal dimmed out in a unique way, characteristic of Mars' atmospheric properties. Half an hour later, the machine emerged already playing back from one of its two tape recorders the evidence collected in its whirlwind visit to the planet.

As it slowly recedes, still jabbering of gas spectra, picture elements, and instrument temperatures, a second visitor is on the doorstep of Mars. Mariner VII is already feeling the pull of alien gravity. Soon it will warm up its telescopic television cameras, swivel its big silvery head, and start taking pictures at long range. Then it will repeat its elder brother's wide-eyed zigzag scan over the planet in the feverish half-hour close to the Martian surface. Finally, it too will duck out of sight of Earth, and come back spewing out the results of its observations.

Within a few days, all the scientific information will have been returned to Earth. The spacecraft will sail on, their principal voyage done. The giant antennas back on Earth will find other radio voices to listen to; the engineers, other devices to design. The scientists will be working vigorously to interpret the numbers returned by the two Mariners and read from them the new, expanded story of Mars. They hope for as much new knowledge from this mission as we have ever gathered before. But they will want still more. Each day answers yesterday's questions, and asks tomorrow's. So let it be with the 1969 quest of Mariner VI and Mariner VII.

Mars: the Far Shore

The word "planet," from a Greek word meaning wandering, was adopted to describe those celestial bodies, including the Sun and Moon, which wander about in our skies independently of the self-consistent stars. The ruddy planet Mars is the very paradigm of wanderers, making its irregular way from West to East through the constellations of the zodiac about every 23 months, and passing from conjunction to opposition and back to conjunction every 25 to 26 months.

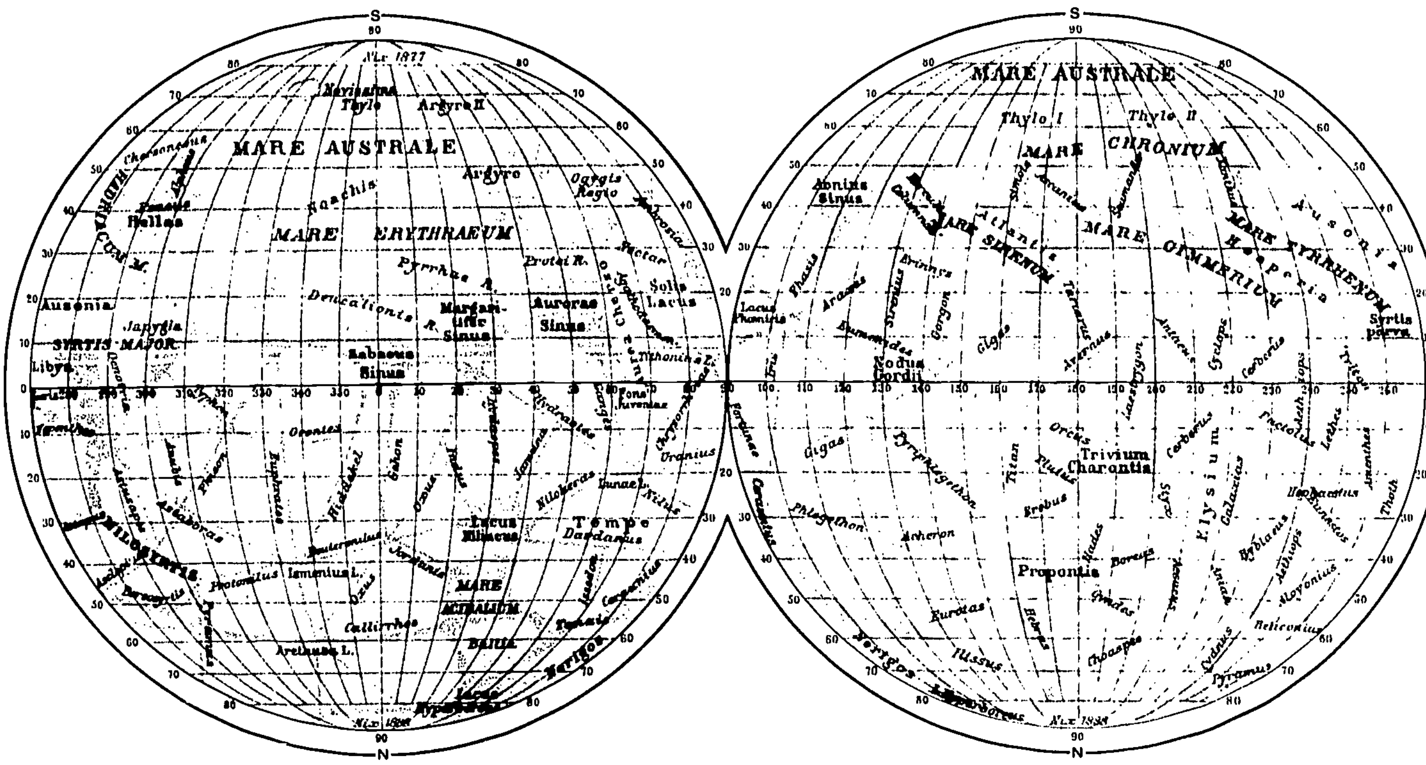
For about two to three months surrounding its opposition to the Sun, Mars reverses its motion against the stars, moving from East to West. Combining this reversal with its North-and-South motion in our sky, the planet traces out a pattern which may resemble the figure 9 or 6, or the letter S or Z, depending on the year.

Changing Views

This eccentric motion through the sky, which is performed with variations by all the planets, brought about the ultimate downfall of the Ptolemaic hypothesis of the nature of the solar system. The Greek Ptolemy and his followers held that the Earth is the center of all things, which orbit variously about our planet. Tycho Brahe carefully measured the positions of Mars during all its oppositions from 1580 AD to 1600, and his colleague and successor, Johannes Kepler, worked for several years to fit the data to a theory which became the foundation of our current understanding of planetary and celestial motion: the heliocentric ellipse and the nature of motion in it.

Kepler's first law, propounding the elliptical orbit, was published in 1609; the same year, Galileo observed the changing phases of the planet Venus as it traversed its orbit, but could not confirm the more subtle changes in the shape of Mars' disk. Still he observed, believed, and taught, in the face of powerful but scientifically untenable opposition, that the planets are orbs like our own, moving around the Sun as does our Earth.

Before the century was out, other observers, using better telescopes, had noted and drawn distinct



Map drawn by Giovanni Schiaparelli from observations between 1877 and 1888. Note that south is at top according to astronomers' convention.

surface features, including the south polar cap, and had found that Mars rotates on its axis in 24 hours 40 minutes, a figure within three minutes of the currently accepted one. Surface changes, seasons, and other similarities to Earth were brought out in the eighteenth century, together with the assumption that Mars was habitable and inhabited. By the nineteenth, a number of observers were compiling maps of the planet and assigning names to the features. Richard Proctor produced one map, calling the dark areas seas and the light areas lands, and naming them after astronomers and scientists, with the English observers predominating. Camille Flammarion drew another, naming the features in the French language and modifying Proctor's scheme somewhat. Giovanni Schiaparelli, using the opposition of 1877 as his observational base, produced a new map with a new series of names, in Latin, using extant or mythical terrestrial features, which became the foundation of modern areography or Martian geography.

The American Astronomer Asaph Hall discovered Mars' two tiny satellites in August 1877, a very favorable opposition of Mars. He named them Deimos and Phobos after the two squires (or in other references, horses) of the antique God of Battle. Using a lucky numerological scheme, Kepler had predicted (and *Gulliver's Travels* had suggested) that Mars had two moons, but their small size postponed actual discovery until observing techniques and equipment had improved. Phobos turned out to be so close to the planet, and therefore, so speedy in its near-circular orbit, that it orbits faster than Mars rotates, rising in the West and setting in the East twice a day. Deimos, further out, completes each orbit in about 30 hours, with the planet turning under it in 24½ hours, so that it appears to move slowly across the sky from East to West every 5½ days.

Analysis at a Distance

Spectral study of Mars began in 1862, shortly after the invention of the technique, but for 85 years little more was demonstrated than that Mars shone in reflected sunlight. The last two decades have seen Martian spectroscopy triumph over the dimness of Mars, the brilliant diversity of the solar spectrum, and the thickness of Earth's atmosphere. The first constituent of the Martian atmosphere to be identified was carbon dioxide, found by G. P. Kuiper. Discovery of water vapor followed, when the planet was receding from the Earth, and its spectrum was shifted slightly off that of Earth's atmosphere by the doppler effect. Careful analysis of carbon dioxide absorption lines suggested that the total atmospheric pressure was much less, and the percentage of carbon dioxide much greater, than previously believed. A vigorous search for spectroscopic evidence of oxygen was not successful, although theoretical models suggest a small amount of the element in Mars' atmosphere.

An improvement in the observation of Mars comparable to the invention of the telescope and spectroscope came in the early 1960's with the development of a machine to carry remote-reading instruments close to Mars. Mariner IV, the first such machine, made possible the investigation of the planet's gravitational and magnetic fields on the spot, the photography of a portion of its surface from a distance of a few thousand miles, and the penetration of its atmosphere by a precisely measured radio beam. Prior estimates of the magnetic field strength and surface-level atmospheric pressure were revised downward as a result of the 1965 spacecraft encounter. The surface was observed to be cratered, much like that of the Moon, a condition which had been predicted in the 1950's by Opik and Tombaugh, but still came as a considerable surprise to most observers. The general trend in modeling the conditions on Mars had been in a direction away from the earthly and toward the lunar; in particular, the estimates of surface atmospheric pressure had been falling steadily. But still the idea of another terrestrial world died hard.

A Contemporary Survey

The post-1965 model of the fourth planet was unearthly and hostile by our standards. Where the Earth is generally thought to have a molten-metal core bounded by a solid mantle of similar composition, with a thin rocky crust, the interior of Mars was now believed to be far simpler. It is probably nearly homogeneous throughout, with far less free metal, if any. The negligible magnetic field (below the threshold of Mariner IV's instrument) was predicted by some planetologists, who thus found their ideas about the planet's inner structure partly confirmed.

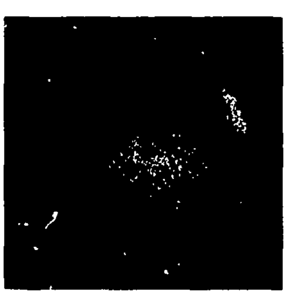
The surface of Mars shows greater relief or altitude difference than would be expected in comparison with the Earth. Craters photographed by Mariner IV show substantial local relief. Based on the 1965 observation of perhaps 278 craters, at least part of Mars' surface must be topographically very like the rugged highlands of the Moon. Unlike our big satellite, however, Mars is relatively brightly colored, with large dark and light features around the globe, and a generally orange cast.

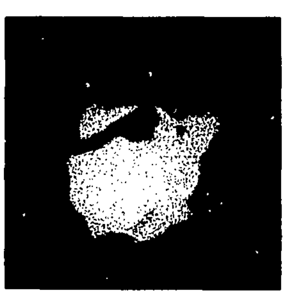
At its mean orbital distance, Mars receives only 43% as much solar energy per unit area as the Earth. Its surface temperatures for various locations and times of day are therefore colder than those on Earth. In the current southern-springtime season, for example, surface temperatures along the equator are believed to run from -80 to -155°F at dawn, rising to an 80°F peak around noon, and falling to -65 to -100° at sunset. The polar regions are thought to vary from about 20°F in local summer to -200°F in winter. Lacking Earth's oceans, which serve as a planetary heat sink and keep the daily cycle within tolerable limits, Mars' temperature is essentially dependent on solar radiation, and hence on season and local time of day. The surface appears to be a poor heat conductor. It is well to bear in mind that this part of the model of Mars' conditions was based entirely on data received across 35 or more million miles of space and through Earth's deep and active atmosphere, conditions which argued strongly in favor of the Mariner Mars 1969 experiments.

Having an atmosphere, Mars has weather, and clouds; its poles have white caps of ice and/or frozen carbon dioxide, which shrinks in summer by evaporation into the atmosphere. Liquid water could be only a very temporary feature of the surface; no more than a trace of water vapor could be detected in the atmosphere.

As for life on Mars, only the most direct observations could discover it, and only more of the same could rule it out. Spectrochemical analysis of the atmosphere, a map of the surface temperature, and a high-resolution visible search for habitable terrain could provide strong clues. But all these things were still in the future.

Earth-based photographs taken during the 1969 opposition of Mars as part of the NASA-sponsored observing program.





Mariner the Planet Rover

As a concept, Mariner is ten years old. When the unmanned exploration of the Moon and planets was first being planned in the context of a just-demonstrated space flight capability, the idea of an attitude-stabilized, solar-powered planetary fly-by spacecraft was a major item.

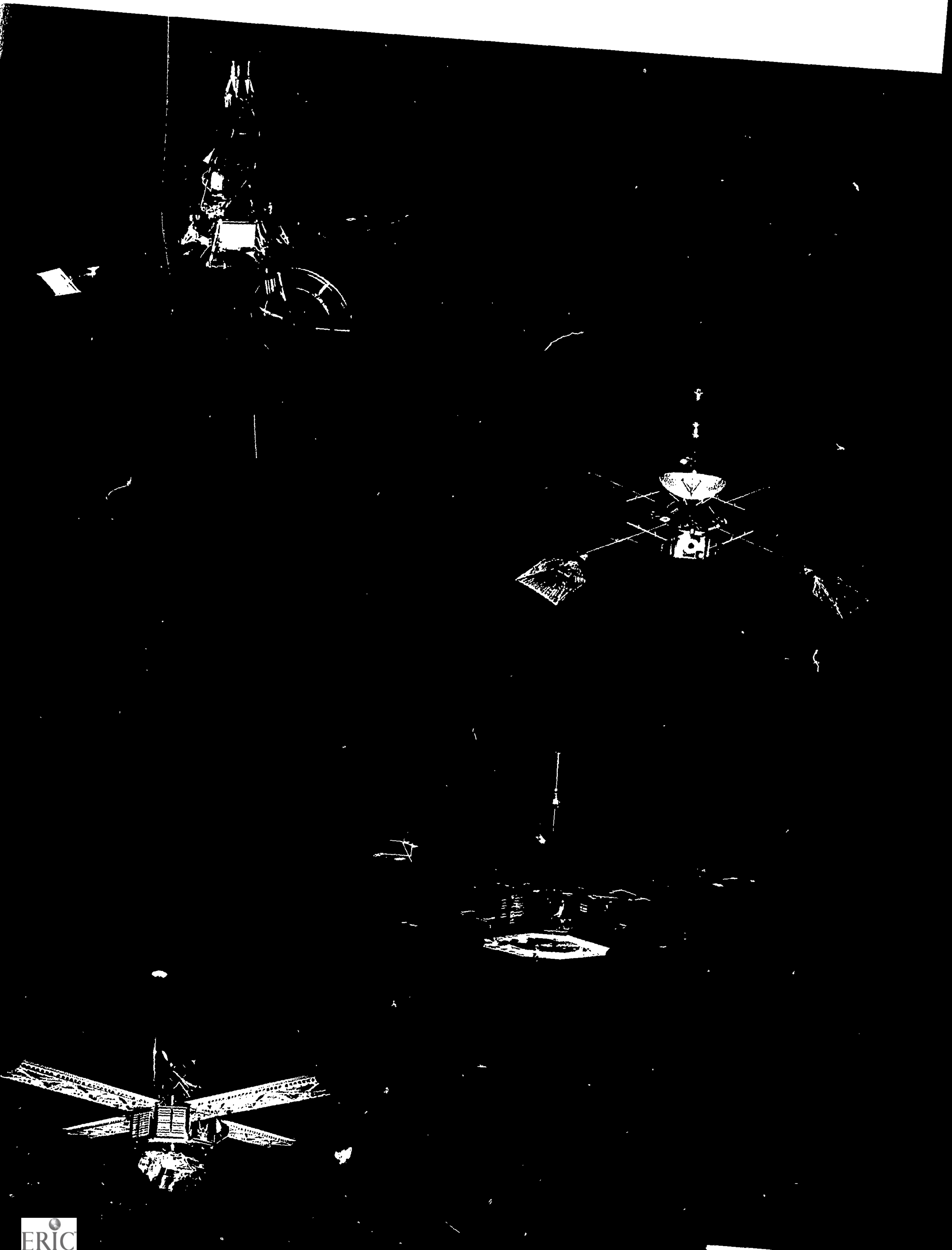
Mariner shares fundamental space flight principles with many other unmanned spacecraft, including applications satellites, orbiting observatories, and Pioneer deep-space probes. These principles include the capability to operate in space for months, perhaps years; the ability to perform at least one thrust maneuver after the initial launch phase, in order to refine or augment the flight path provided by the launch rocket stages; and the maintenance of continuous radio contact with Earth, providing for accurate radar tracking, extensive telemetry return, and response to commands. A major difference is that most of the other vehicles are stabilized only in one axis, usually by spinning about that axis, and tend to have a circular or cylindrical symmetry.

With the other fully attitude-stabilized spacecraft, which have included a few Earth satellites and most of the unmanned lunar investigators, Mariner shares the ability to point solar panels at the Sun, antennas at the Earth, and scientific sensors or cameras at their targets of interest. These craft tend to be in the size range of from 500 to 1000 pounds and to resemble large mechanical insects rather than small robot rocket ships. Mariner differs from the rest by having to travel for months and for hundreds of millions of miles to conduct its primary mission at an interplanetary distance from its home base.

The Interplanetary Family

The 1969 Mariner is the fourth generation of its family to be designed, and the third to fly a mission. In the early days of space exploration, while Ranger missions and spacecraft were being developed for lunar work, two larger planetary craft called Mariner A and B were designed. Like Ranger, they could not

Facing, from top: Mariner II (1962), Mariner IV (1964-65), Mariner V (1967), Mariner Mars 1969 spacecraft.



orbit or land on their targets; but to protect possible Martian or Venusian life from contamination, and for other reasons, they were, unlike Ranger, to miss their targets, making observations during a brief close pass. Mariner A was designed for a Venus mission, Mariner B for a Mars flight. They were one size larger than Ranger, and since a larger launch vehicle had not been developed at that time, were not committed to fabrication and flight.

Instead, in 1961, the Ranger lunar design was modified and combined with elements of Mariner A to produce a 450-pound planetary spacecraft to go to Venus. After an aborted first launch, Mariner II was launched on August 26, 1962, and flew by Venus after a tense three months' interplanetary flight, the first of its kind in history. The spacecraft provided the first close-up observation of Venus, as well as a long examination of the interplanetary medium and the first operational experience of a planetary mission.

Immediately a Mariner Mars project was set in motion, for the 1964-65 flight opportunity. The new space machine was in the Ranger weight class at 550 pounds, but hardly resembled its ancestor otherwise. Ranger had been designed to work in the earthly regions of the solar system. Its close relative, Mariner II, designed to operate in the warming orbit between our world and Venus, had, in fact, suffered greatly in its long, hot journey. The new Mariner had to work in the cold outer regions — the orbit of Mars is half again as far from the sun as Earth — and to operate for eight months before sighting Mars. It had to carry a record payload of scientific equipment and communicate across record distances (130 million miles when it reached Mars). Jamming all these capabilities of communication, electrical power, guidance and control, thermal conditioning, mechanical design, and science, into a quarter ton of mass was a singular achievement of engineering.

The second Mariner effort was also jinxed in the first launch, but after a feverish and triumphant recovery effort Mariner IV began the first flight from Earth to Mars. It fulfilled all its objectives, flying 6000 miles above Mars on July 15, 1965. Then it passed out of communication range, traveled behind the Sun, and reappeared to provide additional interplanetary data and complete three years as an operating man-made planetoid late in 1967.

The New Generation

The spare spacecraft from the 1964 Mars mission was redesigned, rebuilt, and re-equipped for a Venus flight in the summer and fall of 1967. The Mariner V mission was conducted at a time of very active planetary research, including the Soviet Venus-atmosphere probe Venera 4 and Earth-based radar examination of the planet. Mariner V shed new light on the hot, clouded inner planet, and on the weather of the solar system. It also advanced the techniques of building and operating planetary spacecraft, as had each Mariner in its day.

Meanwhile a new, larger Mariner was about to be born. Formally authorized on December 22, 1965, the Mariner Mars 1969 Project was originally expected to take a modest next step beyond Mariner IV, a mission just concluded at that time, and to set the stage for later, more ambitious Mars landing missions which would undertake the search for extraterrestrial life.

Because of the availability of the Atlas/Centaur rocket, locomotive of the Surveyor lunar landing mission, the 1969 Mariner could be heavier than its forebears, somewhat easing the strain imposed on the designers of Mariner IV. But the successful 1964 design would be changed only to improve mission reliability, to reduce cost (by eliminating expensive minimum-weight designs), or to accommodate the differences of the 1969 mission or the new payload. As these factors came into closer focus, the 1969 Mariner evolved from a beefed-up Mariner IV into a mature design with its own character and qualities. Externally, from a reasonable distance, its similarity to the first Mariner is striking. But in many critical aspects it is a new species of spacecraft.

Dockside Interplanetary

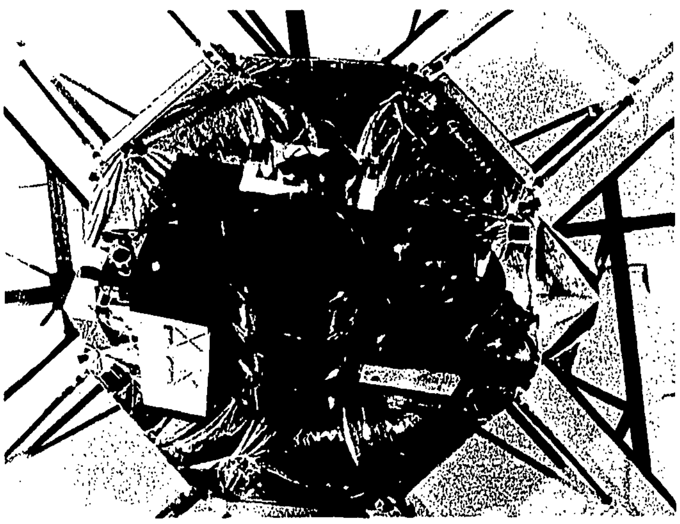
Mounting and equipping an unmanned interplanetary expedition is one of the most challenging of technological endeavors, for two reasons: timing and irreversibility.

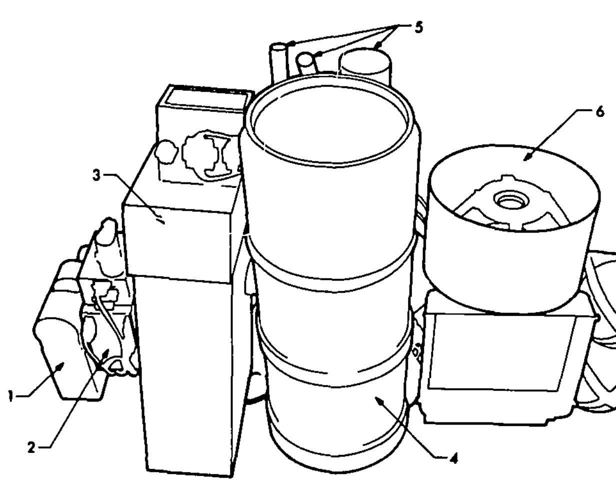
The energy requirements for interplanetary flight are exceedingly high, fluctuating with the differential rotation of Earth and the target planet between utterly impossible and merely difficult. Launches to Mars with an acceptable energy cost can be attempted just about every two years, when Earth is roughly thirty to forty-five degrees behind Mars in orbit around the Sun. The greater an energy cost (or spacecraft weight penalty) a mission can afford, the longer this "planetary launch opportunity" can be stretched. But within a month or two, the opportunity runs out, and one must sail at once or wait two years.

The previous Mariners each started development shortly after one launch opportunity, and had to leave Earth at the next. There was time to do more for the 1969 project, in science and spacecraft engineering and operations training, but there was no added margin in which to make and correct mistakes. Everything had to be very nearly right the first time.

Once an interplanetary vehicle is launched, there is no turning back. The ship and its mission are committed to a journey which will take months before the objective is sighted. There can be no pit stops, no heaving to for repairs, in the race to Mars. There can be no more than the very limited operations of switching to duplicate equipment, automatically or by command, in the event of failure. If the difficulty goes beyond these options, the mission can only suffer.

Thus the calculation of risks, and covering them with redundancy whenever possible, takes on a high priority in a Mariner effort. At the very simplest level, this means sending two spacecraft if it can be done. It was done in the 1962 and 1964 projects, and in each case the first spacecraft did not survive the launch for reasons quite beyond its control. There would be two launches in 1969.





Mariner's heavily-laden scan platform is shown above, and the instrument passengers are seen separately below. The temperature-control blanket (like that stretched over the octagonal spacecraft body) has not yet been installed on the platform. The instruments are (1) the infrared radiometer, (2) the wide-angle TV camera, (3) the ultraviolet spectrometer, and (4) the narrow-angle TV camera telescope. Planet sensors which help control scientific operations are marked (5), and (6) is the infrared spectrometer.

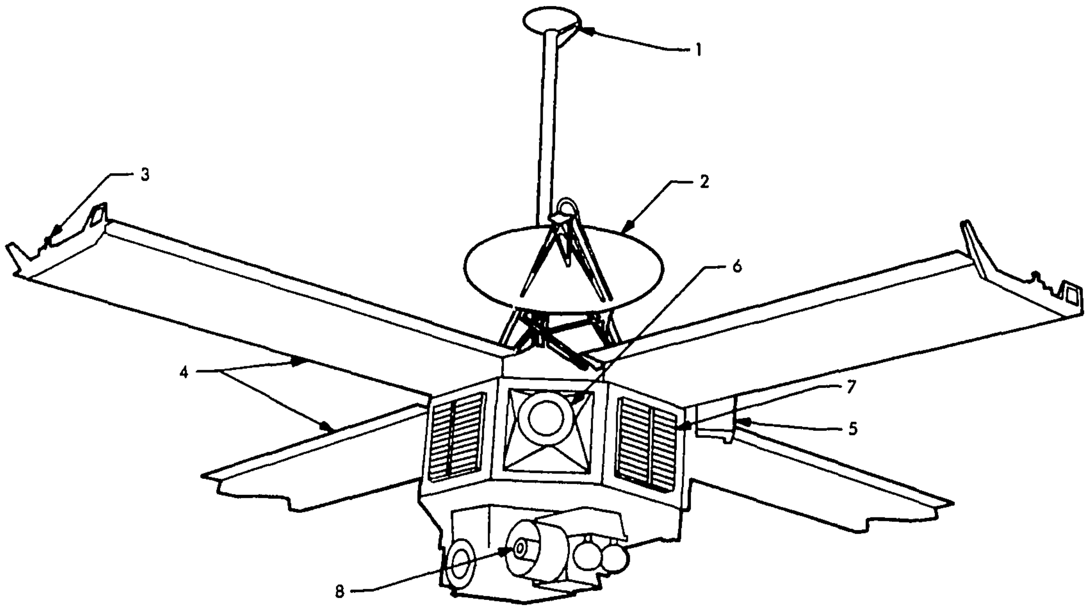
Concentrating on Mars

Early in the development of Mariner Mars 1969 came a decision which was to determine the character of the mission in a proliferating way. In selecting the scientific experiments to be performed, NASA deliberately made this the first truly planetary mission; of the six experiments, none would start until the spacecraft reached Mars. This contrasted with previous Mariner science efforts, which began studying the interplanetary medium near the Earth and obtained more data en route than on arrival, though the planetary objective was always primary. In addition, the scientific instruments carried by the two 1969 spacecraft were to be pointed at specific regions of the planet — instead of making a simple sweep over the disk — and were to produce near Mars, for storage and return to Earth, more scientific data than had the previous Mariners in their combined flight lives.

The six scientific experiments selected by NASA for Mariner Mars 1969 were to be supported by two television cameras, ultraviolet and infrared spectrometers, an infrared radiometer, and the spacecraft tracking and telemetry link. Astronomers, geologists, physicists, chemists, and biologists would study the atmosphere and surface of Mars through the various radiation-sensing instruments, and physicists and mathematicians would use the occultation or extinction of the radio signal as each Mariner passed behind Mars to probe the atmosphere and define the surface beneath, and the tracking information to study the gravitational fields through which the spacecraft moved, thereby measuring the mass and motion of Mars.

The surface-scanning instruments were mounted on a large turret on the antisolar side of the spacecraft. Weighing nearly 200 pounds fully loaded, and guided by sensors and electrical angle measurements, this scan platform could move 70 degrees in elevation or cone angle, and 215 degrees in azimuth or clock angle, at a rate in either direction of one degree per second. The scan platform moved in response to instructions from the spacecraft computer, which was also a new thing with this mission.

The computer developed and flown on Mariner VI and Mariner VII had a memory storage of 128 words of 22 digital bits each. It could be programmed and reprogrammed, before launch or in flight, as late as minutes before the programmed events were to take place. It could read out its memory to the operators on Earth before and after changes. Most important, it could control events as simple as switching off a circuit or as complex as an entire Mars encounter sequence.



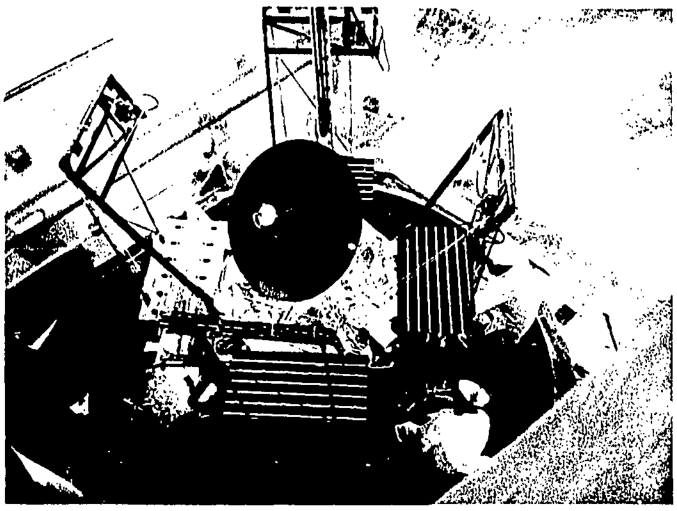
The Mariner Mars 1969 spacecraft design. Commands are received over the omnidirectional antenna (1), which also transmits to Earth until, toward Mars, the high-gain reflector antenna (2) is lined up by the spacecraft's position. Tiny cold-gas jets (3) on the tips of the solar panels (4) position the spacecraft so that the Sun is overhead in the view shown. Photoelectric sun sensors on the top of the spacecraft body, invisible in this view, provide the main reference for this orientation, so that the solar cells on the upper surface of the panels may convert sunlight into electric power. The Canopus tracker (5) provides an additional reference, keeping the spacecraft from rolling around the Sun line. The maneuver engine's nozzle (6) points sideways out of the spacecraft; the whole machine is turned by the gas jets to point the rocket in the proper direction. Most equipment is inside the octagonal body; it is kept at the proper operating temperature by insulating blankets above and below and by louvers (7), which do not ventilate but change the heat radiation under thermostatic control. The scan platform (8) points the scientific instruments (see facing page), rotating or elevating on command of the spacecraft computer.

The Information Problem

These features gave each spacecraft the ability to acquire more bits of scientific data near Mars than all previous Mariner missions had obtained, as we noted previously. The problem then became one of how to return this vast pool of information to the scientists on Earth.

The preceding Mariners had used a tape recorder to store the scientific information acquired at the planet in a few minutes and return it more slowly to Earth over a period of several days. But the Mariner 1969 system could gather far too much information about Mars for the tape recorder to hold, even if the tape was lengthened, the number of tracks doubled, the density of information put on the tape increased nearly to the bursting point, and a second tape recorder added to the spacecraft. And the information had to go through the tape recorder, for the spacecraft could not transmit fast enough to relay directly to Earth. Or could it?

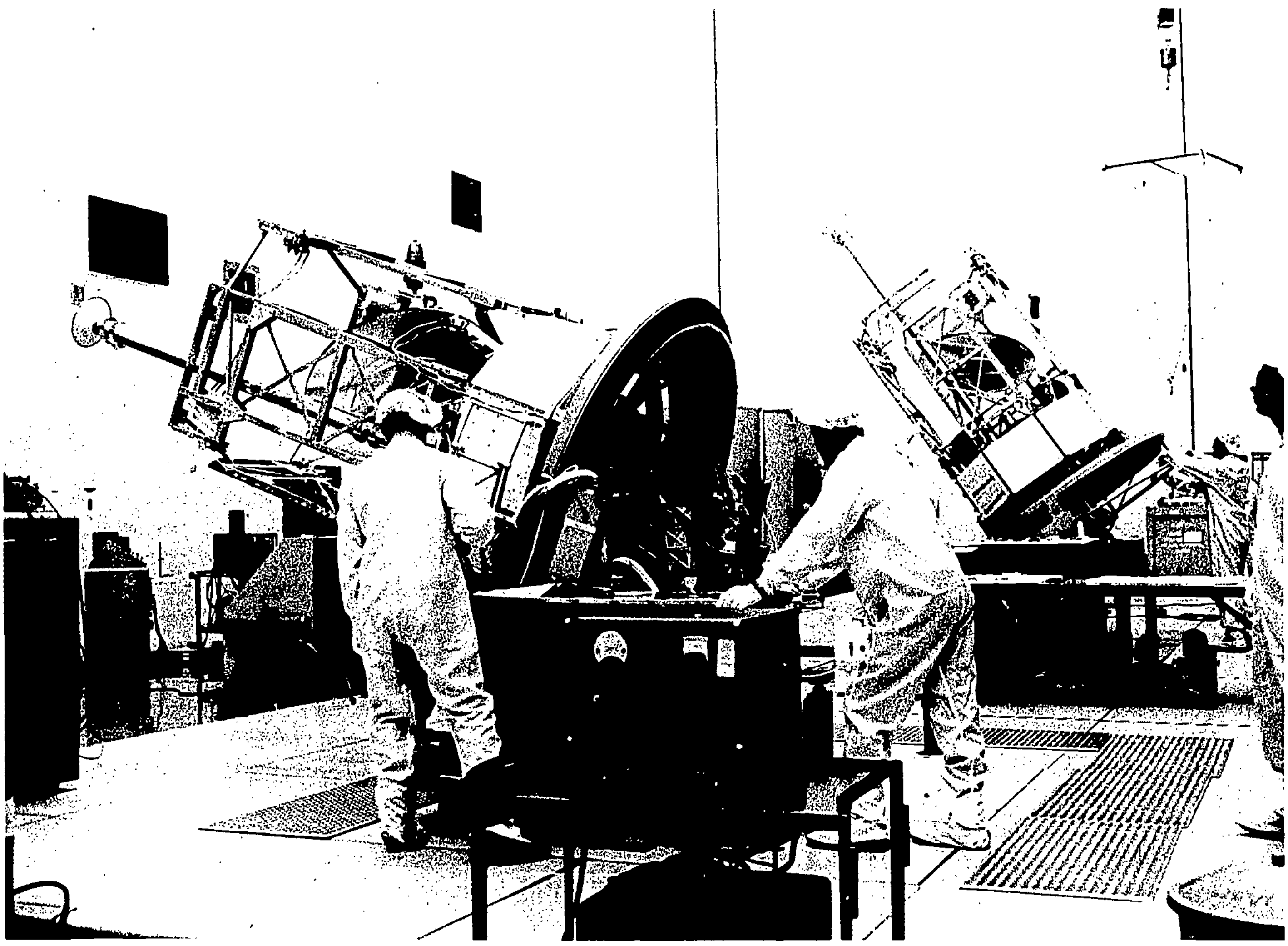
Space communications have come a long way since the first simple Earth satellites. In the planetary missions, the increase in distance had matched the advance in technology, so that in 1965 Mariner IV had transmitted from Mars to Earth, a distance of 120 million miles, at a rate of only 8⅓ bits per second, corresponding to more than eight hours for each TV picture. But after 1965 space communication took a great leap forward; furthermore, the geometry of the 1969 mission reduced the communication distance to 60 million miles. The spacecraft carried a more powerful transmitter and a large transmitting antenna, while the advanced antenna system at Goldstone added a 210-foot-diameter dish antenna to a network of 85-footers, and backed it with new and very sensitive receivers. The experience of the earlier Mars flight had permitted the designers to reduce their safety margins as well. Accumulating many factors of improvement allowed the telecommunications developers to offer Mariner Mars



Above, Mariner spacecraft is prepared for a test in the 10-foot space simulator. Below, Mariner VI and Mariner VII undergo final checkout in the hangar at Cape Kennedy.

1969 an increase in transmission rate of two thousand times, limited to the eight to ten hours per day when the spacecraft was within range of Goldstone, with a backup mode operating on a slower data rate.

This technique offered Mariner's experimenters, especially those concerned with the television survey of the planet, an exciting hope: instead of eight pictures taken during the last day of each approach to Mars, they could gather 160, beginning two or three days out and building an observational bridge from the level of Earth-based views to the final closeups. Ultraviolet spectra and planetary temperature measurements would be available during this period also. The far-encounter views from each approach could be examined before the corresponding close pass, providing an opportunity to adjust the near-encounter program if necessary. Perhaps more exciting was the provision that all of the close-up data except the complete TV pictures would be returned in real time, at the



speed of light, leaving the spacecraft as soon as they were gathered and arriving at the Earth about five minutes later. Thus some of the limitations on the mission because of restricted recording capacity were eased.

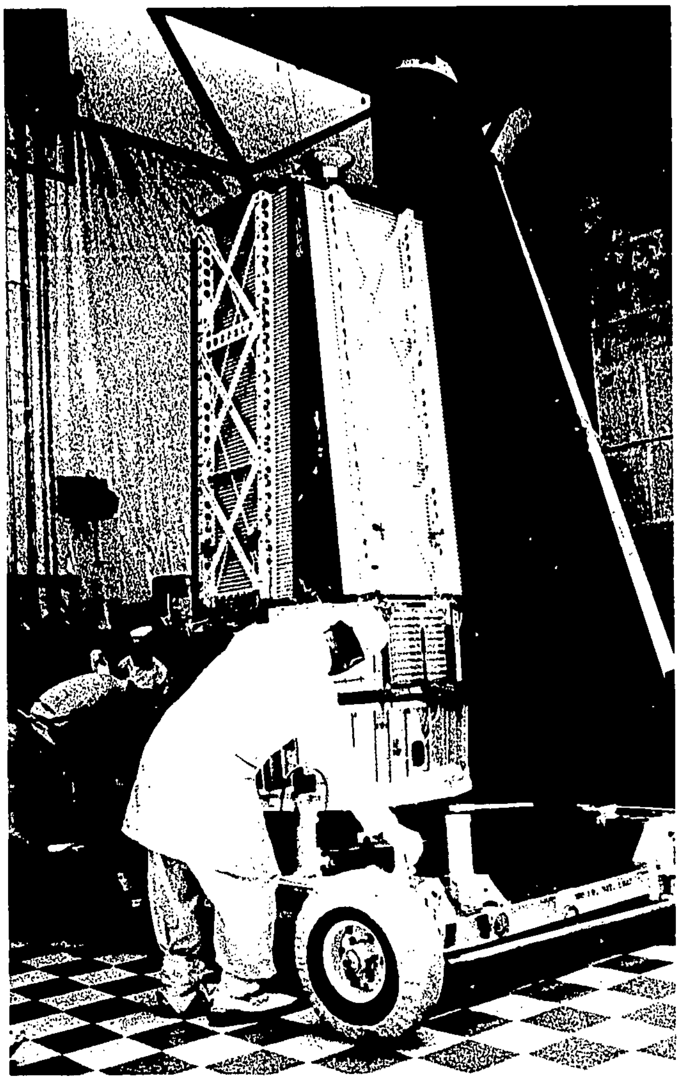
Now to Build It

Now the major design features were settled, and it was time to execute them in hardware. About a dozen spacecraft subsystem contractors had to build the various units, qualify them for flight use, and deliver them. At JPL, they had to be assembled into four spacecraft: a proof-test model, two flight craft, and one assembled set of spares. The proof-test model would never fly; it and its parts would be tested at levels simulating an environment even harsher than that expected in each aspect of the flight to Mars, to qualify the system design for the mission. The other three units would be tested more gently, on the vibration table to rehearse the launch, and in the space simulator to practice the space flight and Mars encounter, in such a way as to save some strength for the real thing.

After many returns to the test bench, and much rebuilding and repairing, the machines were finished. One would never leave JPL in Pasadena, where it would live out its life as a test vehicle. The other three were shipped to Cape Kennedy: two for further shipment to Mars, and one to stand by as a supply of equipment for transplant in the process of diagnosis-and-cure called system test, which would continue right down to the moment of departure.

About ten and a half days before the scheduled launch of Mariner VI, the Atlas/Centaur/Mariner space vehicle was standing on the pad, undergoing a simulated launch with the rocket-propellant tanks empty. Suddenly the Atlas began to collapse like a punctured tire. Most of the structural strength of the Atlas is provided by the pressure in its tanks, a balloon-like design feature which saves a lot of weight. A worn-out relay in the vehicle had opened the main valves, letting out the pressure through six-inch pipes. As the vehicle sagged alarmingly in its gantry, two ground crewmen sprinted for the manual valves inside the Atlas and shut them off. The pressurizing pumps restored tank pressure, and the big rocket resumed its shape, but a terrible scar was visible in its plating.

Within hours the Centaur and Mariner had been returned to their hangars for a quick round of testing which would verify their good health after a narrow squeak. The launch vehicle intended for Mariner VII was commandeered for the first launch. The crew found that they could cut launch preparations from two weeks to one week by working extra hard. A third Atlas rocket was shipped out from San Diego by Convair, to replace the one borrowed from Mariner VII, while the damaged vehicle went back to be repaired and re-tested, and, months later, to serve another mission. The Mariner launch schedule, so severely limited by the motion of the planets, had been saved by redundancy and the provision in the plans for a problem of this kind.



At Cape Kennedy, the spacecraft is installed in the two-piece Centaur nose fairing, which will protect it on its flight from Earth's surface into space.

Thus in the late afternoon of Monday, February 24, the Mariner VI flight was ready to begin. The Mariner VII prelaunch operations had just over a month to run.

Five Months at Sea

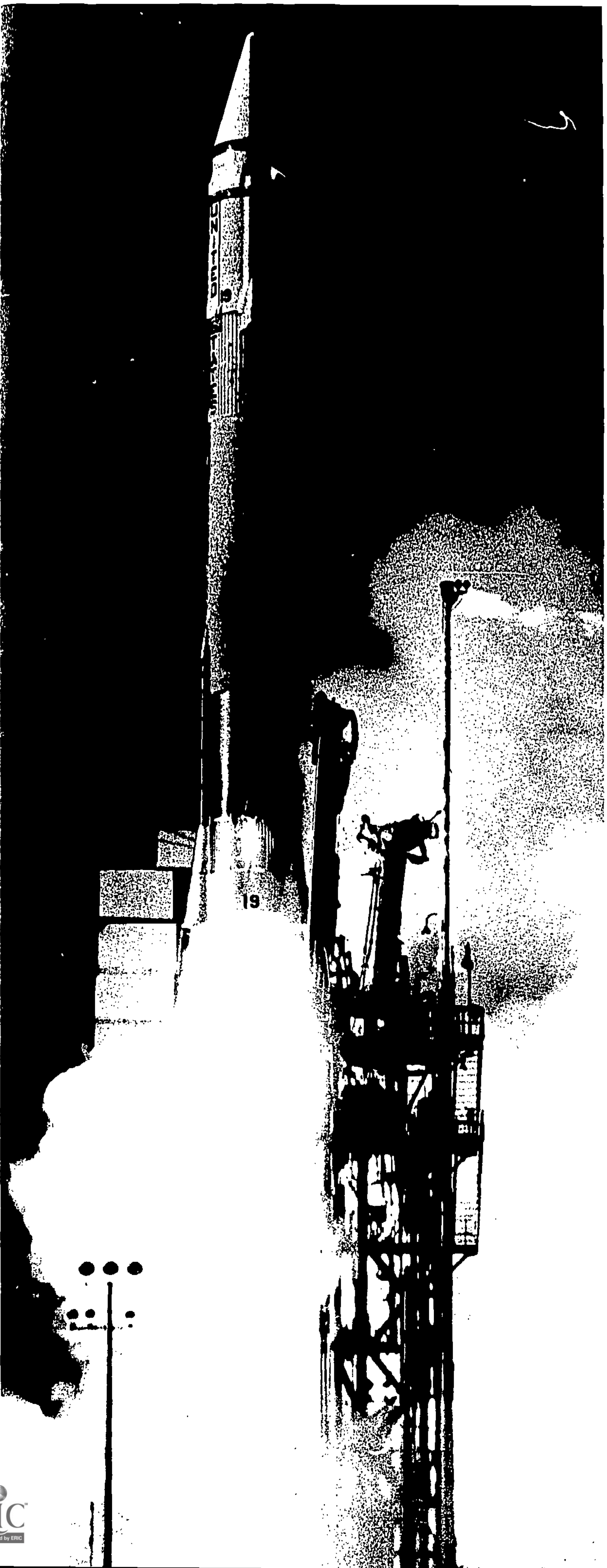
It was about 8:30 at night when Mariner VI pushed off from the Earth. All stages of the intricate launch procedure went off as planned, and about ten minutes after liftoff the spacecraft was in heliocentric orbit, headed for Mars. After another fifteen minutes, it came out of Earth's shadow into the sunlight, oriented itself, and began operating in the normal cruise mode.

An unusual feature of this launch was that the vehicle maneuvered in two directions. Normally, the rocket rises vertically, rolls to the correct heading, and after lifting for some time begins to pitch over so that the final acceleration is nearly parallel to the Earth's surface. Mariner VI's launch had an additional turn, a yaw to the right after the pitch forward, to permit aiming quite far to the south without crossing land areas. The Centaur guidance system, which controlled both the Atlas and Centaur stages, carried out this maneuver.

The Air Force Eastern Test Range tracking net, the Manned Space Flight Network, and the Deep Space Network received and relayed information on the spacecraft's condition and operation back to the Cape Kennedy control room and the Space Flight Operations Facility in Pasadena, where it was duly determined that the mission was going well.

Tracking data showed that the launch was the most accurate in Mariner history. The spent Centaur stage would pass well to the north of Mars, as planned, and Mariner could be shifted down to its flyby of Mars with about 5% of its maneuver capability. The flight path calculations were so good that the maneuver could be conducted four days after liftoff; it was successfully carried out on schedule.

Not quite four weeks later the second bird took flight. This time it was a daylight launch, with the spacecraft passing into Earth's shadow shortly after separation. The Sun sensors had a glimpse of the Sun,



but had to wait half an hour before it reappeared on the other side of the Earth to drive the spacecraft around to Sun orientation. Again, the launch accuracy was outstanding.

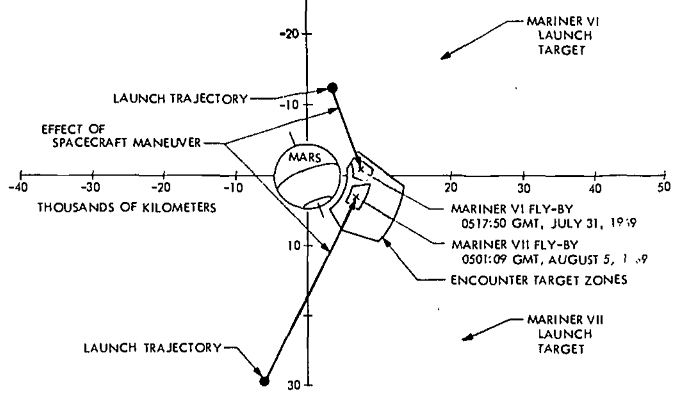
For a number of reasons, principally the desire to get a very precise pre-maneuver trajectory, the Mariner VII maneuver was scheduled for 12 days after launch. It proved to be as successful as that performed on Mariner VI, moving the spacecraft trajectory into its appointed niche above Mars.

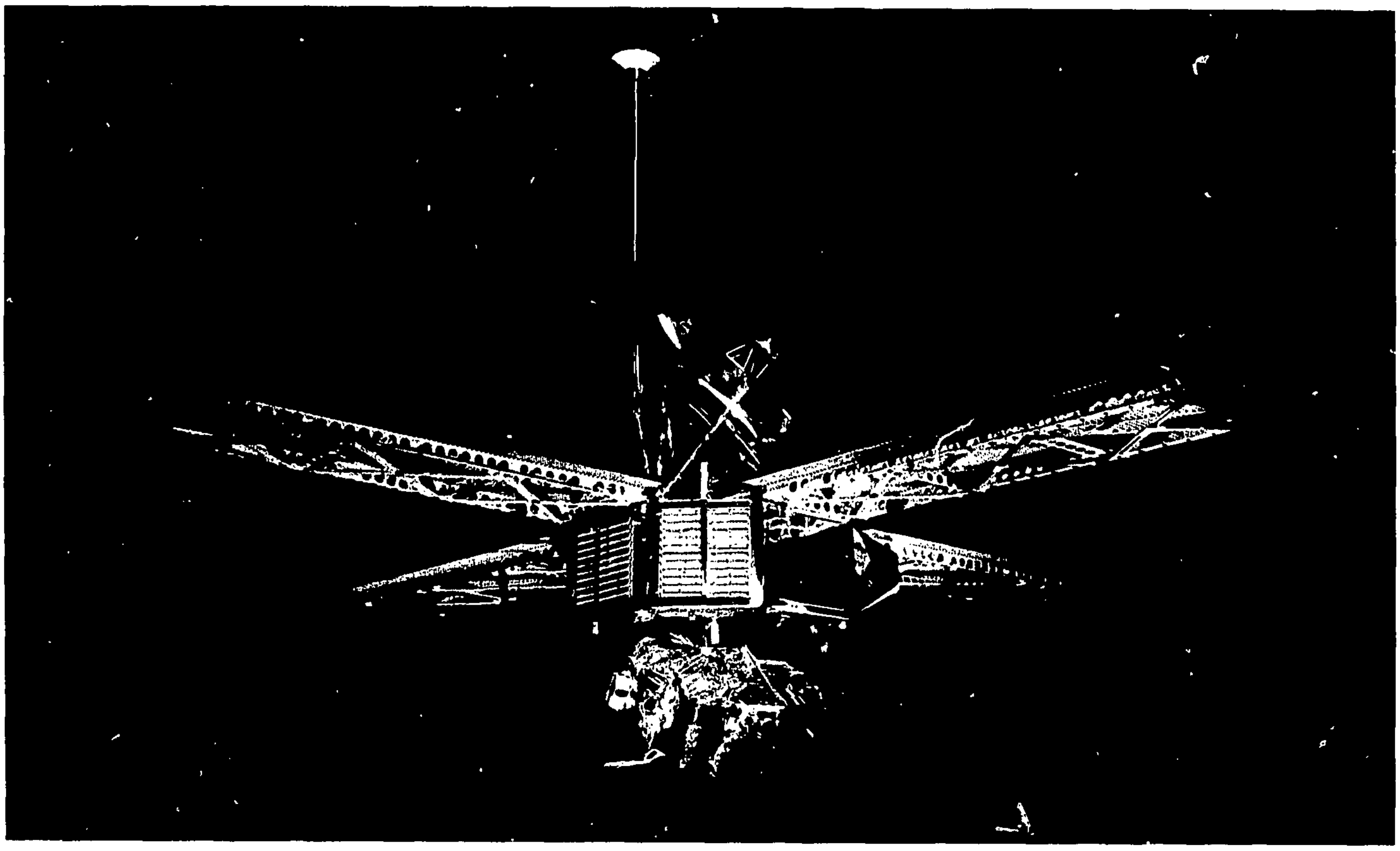
Surprises

With both spacecraft now falling ballistically and inexorably around the Sun toward their planned rendezvous with Mars, and with all operations up to and through that dual encounter already programmed into the two spacecraft computers, the rest would seem to be merely routine. It was the study, review, refinement, possible change, and testing of the complex Mars encounter sequence that was to be the major activity of the period between launch and encounter, occupying many engineers, computers, and days. But spacecraft operators have long since learned to take nothing for granted. Surprise is always just around the next corner.

The first surprise in flight had to do with the radio aboard Mariner VI, shortly after launch. When the ranging channel was on, the radio subsystem tried to lock up on itself rather than on the command and tracking signal transmitted up from the ground; it might then be unable to acquire the ground signal so

Left, Mariner VII launch. Below, Mars-target diagram shows the aiming points and actual destinations of Mariner VI and Mariner VII before and after launch and the spacecraft maneuver. Both missions achieved a closest altitude of about 3400 kilometers or 2150 miles above the surface of Mars.





long as ranging was on. Ranging is a form of two-way communication between spacecraft and Earth in which a radio channel is devoted exclusively to navigation. A recognizable pattern is transmitted to the spacecraft, and turned around and sent back to Earth. The time delay from departure to return is a measure of the spacecraft's distance from Earth, accurate to a few yards. The range measurement normally augments doppler tracking, but in this case ranging was interfering with the frequency matching on which doppler depends. Doppler measures the velocity of the spacecraft from Earth by measuring the change in frequency of the carrier signal — a refinement of a normal radar operation. It requires that the frequency on which the spacecraft transmits to Earth be "locked" to the frequency it receives, to support an accurate velocity measurement.

The problem was ultimately alleviated by keeping the ranging turned off for several weeks. Later in the mission, when ranging was turned on for a test, the radio was mysteriously free of self-lock, and it remained so.

Mariner VII also had radio difficulties, of a different kind. In the first few weeks of flight, the radio receiver dropped to about 20% of its normal sensitivity, apparently because it was cold. Although for a time it was feared that the spacecraft would go completely deaf, the sensitivity fortunately held at that lower level. Later in the mission the transmitter was switched to high power, which warmed the radio compartment, and the receiver recovered and operated normally thereafter.

The Distracted Star Tracker

The Mariner machines (and many others) are designed to maintain a specific orientation in space during almost all their operations. This permits them to point solar panels and heat shields at the Sun, antennas at the Earth, and cameras and other instruments at targets of interest. This orientation is maintained by fixing on celestial references, of which the Sun, brightest star in the sky, is an obvious first choice. Another reference, roughly at right angles to the Sun, must be found. Canopus, about the third brightest star in the Earthly skies, is within about 15 degrees of the south celestial pole, so that Mariner may use it for orientation all the way around its orbit.

Unfortunately, as had been demonstrated in 1964, a brightly sunlit particle of dust dislodged from the spacecraft can drift in front of the star tracker, glittering more brightly than Canopus, and lure the spacecraft away from its proper orientation. When the particle drifts out of range, Mariner must roll all the way around and find its star again. This had happened to Mariner IV, and it proceeded also to happen to Mariner VI. Bright particles were observed during the midcourse maneuvers of both spacecraft in 1969, but the tracker was not in control at the time. When Mariner VI unlatched its scientific platform from the restraints that had protected it during launch, particles were shaken loose which distracted the tracker and made it lose Canopus lock. Since a similar event was scheduled for each Mars encounter, and resulting particles might cause the spacecraft to roll around instead of pointing its cameras at Mars, a solution had to be found.

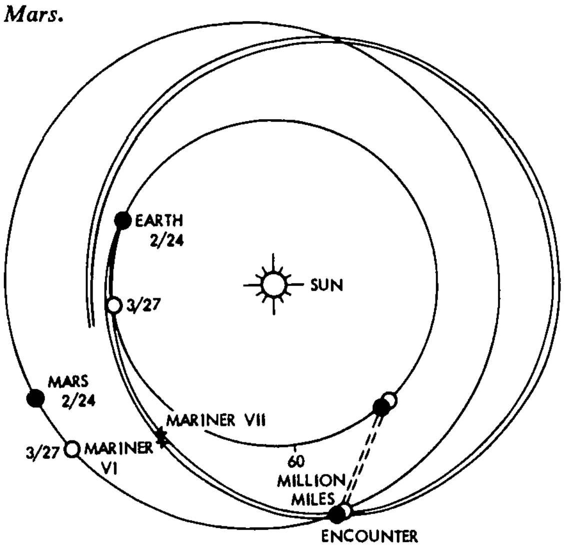
The solution had been built in as an option long before. Autopilots, which keep aircraft, ships, and many guided missiles on an even keel, derive their sense of direction not from the stars but from gyros. Over the long haul, gyros will drift off position and have to be corrected, but for a few days or hours they are accurate enough. Mariner VI and Mariner VII had gyros to hold them steady during the thrust maneuvers carried out a few days after launch. So each spacecraft memory was given something new to remember: gyros on at encounter.

The Great Magellanic Chase

Perhaps there is something sinister about the star Canopus. At least, for Mariner VI, it was once more an unlucky star, which led the spacecraft teams into a frustrating chase through the Greater Magellanic Cloud.

It started on April 20, when the Canopus tracker was supposed to change its cone angle. This change was necessary from time to time because, from the point of view of Mariner, though there is a single point in the southern sky that is always ninety degrees away from the Sun — a geometric south pole — Canopus is not it. As the spacecraft moves in its orbit, always facing the Sun, Canopus appears to circle in the opposite direction, bobbing back and forth about 15 degrees. The sensor must bob back and forth, changing its angle from the Sun electronically to keep the star in sight.

Orbits around the Sun of Mariner VI, Mariner VII, Earth, and Mars.



On April 20, when the computer said "Step the angle," the tracker stepped backwards, losing the star entirely. Ground commands could return it one step, but it would go no further forward.

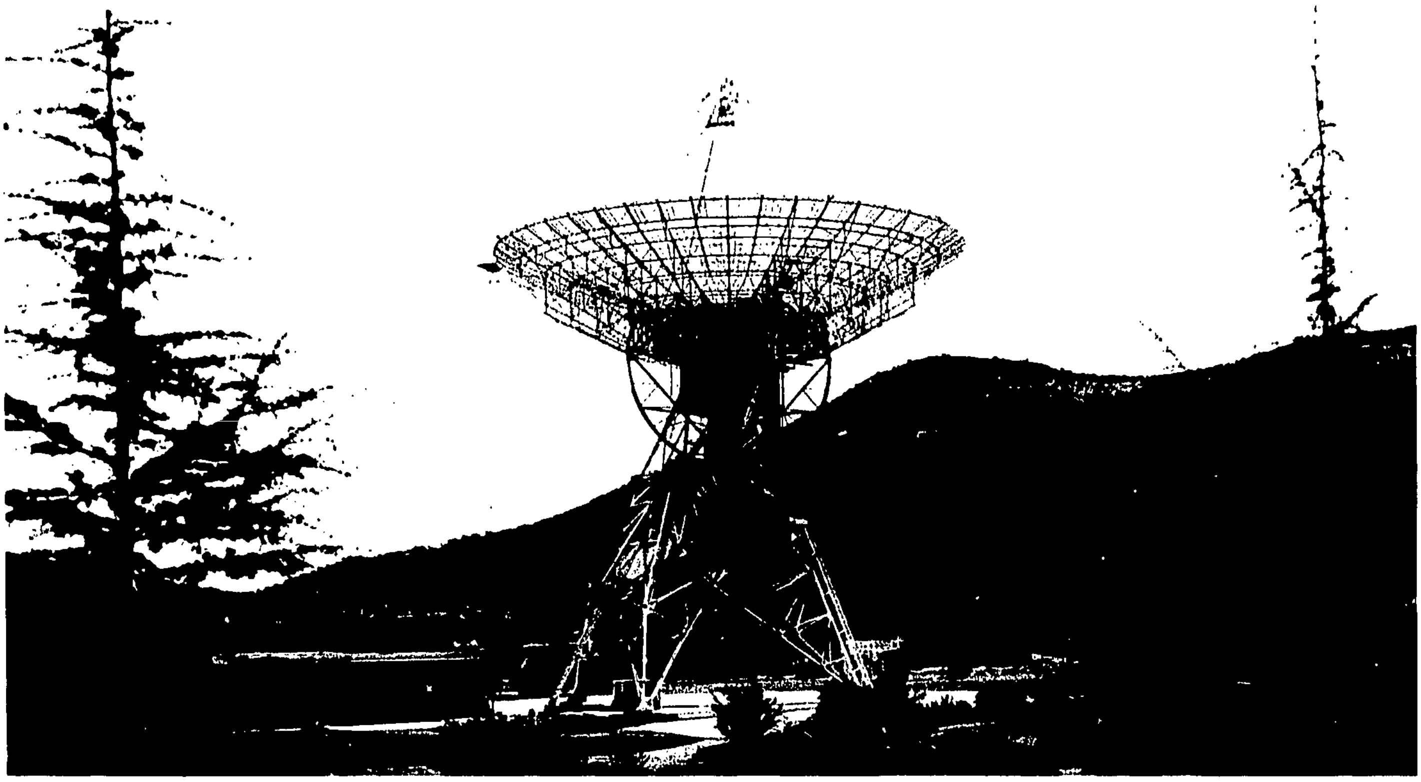
A search was immediately begun for usable stars in the field of view. Earlier, Sirius and Vega had been available, but they were now at the wrong angle. The planet Jupiter would soon swim into Mariner's ken, but it would not stay there till encounter. There was indeed nothing that would serve except the Greater Magellanic Cloud, a nebula hanging above Earth's south pole. It was dim and widespread, a poor navigational reference, but still worth a try.

For days they tried it. If released in roll search, the spacecraft would simply roll past the cloud without stopping. After stepping the roll position — with gyros holding at each step, as they were to do at encounter — slowly through the cloud, and mapping its brightness with the star sensor, the team carefully led the tracker to the brightest part, and then let it go. It stayed, but only for a few hours each time. And the strain of viewing a dim object — like eyestrain — was wearing out the sensor tube. No go.

Next would come another try to change the cone angle with commands, and after that — gyros all the way, perhaps. A barrage of commands was readied — one a minute — to jar the stuck circuit off dead center. Unexpectedly, Mariner VI obediently responded to the first command and settled down again, locked securely on Canopus. Several weeks later, with the last Canopus cone-angle change before Mars encounter, ground commands were again required, and once more were immediately effective.

Alarm of the Dying Sun

One instrument which was not part of the scientific payload nearly produced a scientific sensation. It was a simple absolute radiometer pointed at the Sun by each spacecraft to obtain an accurate record of the solar energy falling on the Mariners as they flew. This information would be of great value in designing future spacecraft, especially their temperature-control coatings and blankets, and the solar simulators in which they are



Johannesburg Station in South Africa.

tested before launch. It would also provide a fairly long-term observation of the solar output from space.

After taking the readings for a few months, the temperature-control engineers concluded with some consternation that the measurements were falling off consistently, confirmed by both spacecraft, at a rate faster than the retreat from the Sun would allow. Either an unexpected affliction had clutched both instruments, or they were showing true conditions and the Sun was slowly going dim. After long sessions with instrument calibration and test records, no theory of radiometer breakdown offered itself. But there was no confirmation outside the two Mariners of any decline in the sunshine. There was nothing to do but wait.

After the Mars mission was safely over, Mariner VI was turned well away from the Sun, so that the radiometer was viewing the cold black sky, and the instrument was calibrated. To the relief of all concerned, the calibration showed that the instrument had drifted. Further analysis led to an understanding and a formula, which, applied to the original measurements, showed a fairly steady Sun with good confidence in the numbers. Corrected to the mean Earth–Sun distance, the average value was 0.1353 watts per square centimeter.

Grand Rehearsal

By June, most of the surprises were behind the two Mariners and their Earthbound crews. Earth had overtaken Mars in their regular race around the Sun, at a closest approach of 44½ million miles, and many scientists were turning telescopic eyes and instruments toward Mars on every clear night. It was not an exceptionally close Mars opposition (not as close as in 1956 and 1971 by ten million miles), but the comparison with spacecraft observations would be valuable.

For the spacecraft and the operations teams it was now a time of testing. All the months of flight to Mars were of little value if the few days near the planet were not perfect. Every act, every ground command, every likely situation was designed, rehearsed, and tested as carefully as the parts of the spacecraft had been, and the engineering measurements from Mariner VI and Mariner VII were carefully assessed to be sure of the capabilities of the hardware.

As June wore on, full-length simulated Mars encounters were conducted for the Mariner VI and Mariner VII sequences, using outputs from the spare Mariner spacecraft. The spare was operated in a building a few hundred yards away from the Space Flight Operations Facility but acted as if it were out by Mars.

July came, and with it a mighty distraction from Mars. The Apollo 11 mission, like Apollo 10, used facilities of the Deep Space Network, including the 210-foot Mars Station antenna which would receive Mariner Mars scientific data, as part of its lunar communication system. A set of DSN stations around the world also backed up the Manned Space Flight Network. Also in July, Mariner VI and Mariner VII demonstrated their ability to play out their tape recorders through the high-rate telemetry link, erase the tapes, and reload them.

Now they were ready for Mars.

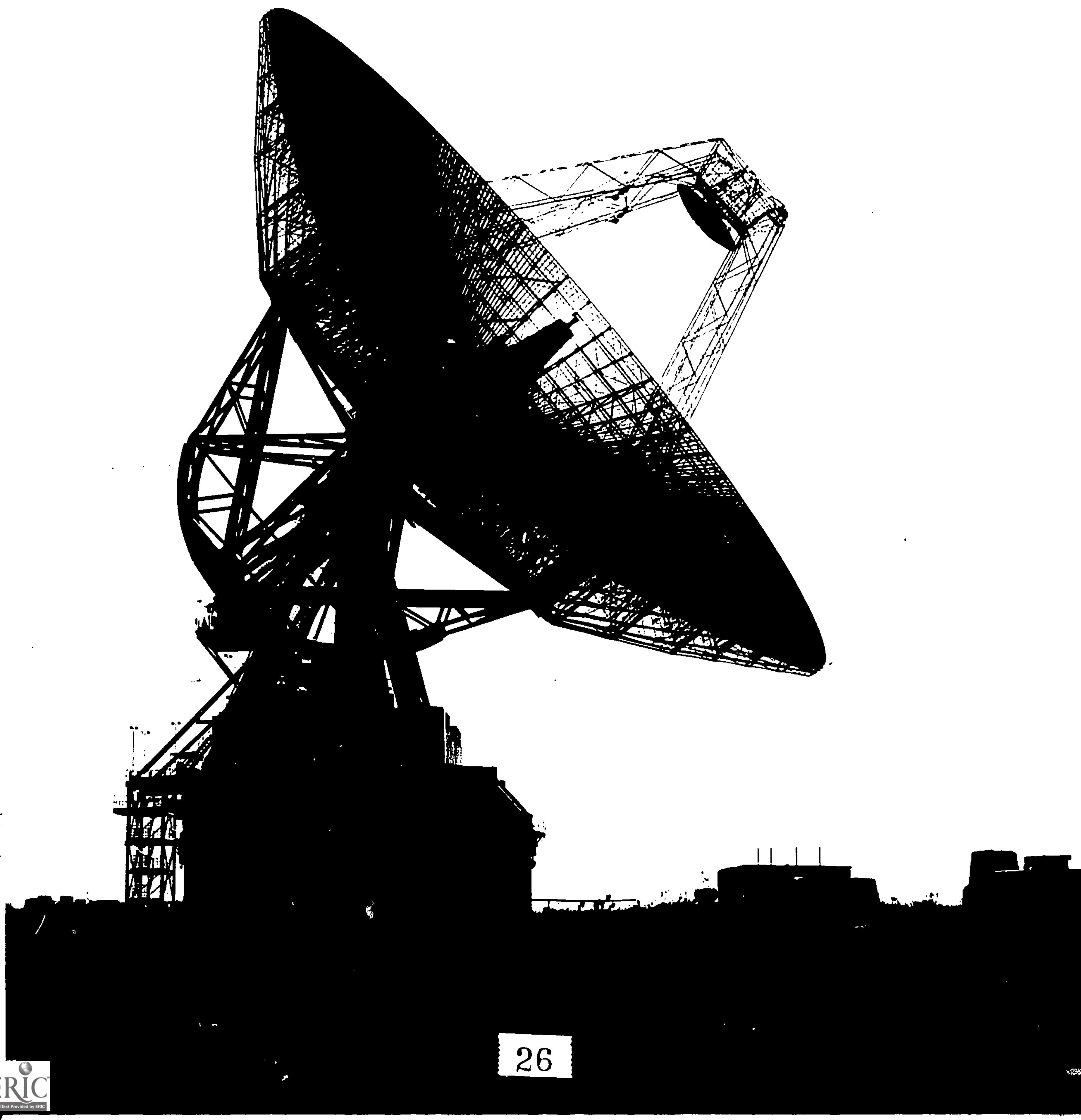
Mars Week

It began for Mariner VI some 154 days after launch, with Mars some 780,000 miles ahead. Back on Earth, at the Jet Propulsion Laboratory's Space Flight Operations Facility, it was Monday evening, July 28, 1969, when the first far-encounter commands were sent to the spacecraft. The scientific instruments were turned on, and the scan platform was moved around to verify its operation, before pointing at Mars. Then the lens cover was removed from the narrow-angle television camera, and the sequence of recording 33 television pictures at 37-minute intervals was begun.

First Look for Mariner VI

After a few hours, the high-rate telemetry link was turned on to allow the return of data not being recorded. About twelve minutes later, a rough engineering-model picture of Mars arrived in Pasadena. Most of the planet was blotted out by a black vertical stripe, set aside from this picture format for the transmission of ultraviolet and infrared measurements which were being processed in another part of the ground computer system. The image was coarse and ragged, for (outside the stripe) it was built from only one-seventh of the picture information gathered by the camera. But it was visible proof that Mariner VI was doing its job.

Through the night and the next day, the spacecraft tape recorder continued to gather a series of 33 television pictures of Mars. In the afternoon, when Mars and the spacecraft again rose above the horizon of the great 210-foot Deep Space Network antenna at Goldstone, the high-rate telemetry was turned on, and another stream of engineering-model pictures and ultraviolet and infrared measurements began to flow across almost sixty million miles of space. By evening, the spacecraft tape recorder was full, and about 6:30 p.m. the controllers in Pasadena instructed the spacecraft,



now some 450,000 miles from Mars, to play back the tape. Again there was about a twelve-minute wait. Then the first complete picture, recorded the evening before, appeared on the monitors and was transmitted to television networks and local stations. In a room deep inside the Space Flight Operations Facility, the Principal Investigator of the Mariner Television Experiment watched as one view of Mars succeeded another, the grey globe against black sky slowly rotating and growing from picture to picture. "Beautiful," he said, "that's beautiful!"

When the three-hour playback was done, and the experimenters were already studying fresh prints of the pictures with caliper and magnifying glass, the spacecraft was commanded to erase the tape, and then to begin a new series of far-encounter pictures, at about 340,000 miles from Mars. This series would be only half as long, for it was scheduled to end 7½ hours before the spacecraft came close to Mars, to allow full time for preparation for that important event. Wednesday evening would see the playback of these seventeen approach pictures, last-minute preparations for the near encounter, the close-range scientific pass itself, and the beginning of the data playback. Before Mariner VI began its half-hour close pass, the trajectory had to be accurately determined so that instrument pointing angles could be corrected, last-minute checks had to be made, and ground commands, mostly backing up the existing sequence already in the computer, had to be sent. Then the five instruments, including two alternating TV cameras, would automatically start, scanning over the surface in a swath which was zig-

zagged four times by programmed platform slews. Finally, the spacecraft would be occulted behind Mars.

Interruption of a Triumph

Fifteen minutes before Mariner VI took its last far-encounter picture, however, all the alarms rang for Mariner VII, and within fifty seconds its signal had disappeared.

What actually happened to the second spacecraft would not be fully analyzed for months. At the time, it was clearly an emergency, coming exactly at the wrong time. The Deep Space Station which had last heard from Mariner VII kept searching for the signal; presently, other stations of the network joined in. A small team of spacecraft engineers was detached from the crew of Mariner VI, which had priority. They studied the last bits of telemetry, and the occasional flickers of signal which, after a while, appeared in the giant receivers. They concluded that Mariner VII was windmilling through space, torn loose from its line to Canopus, its narrow beam of telemetry sweeping the sky like a searchlight.

After some hours, a command message had been decided upon, together with a way to operate through a system properly belonging at that time to Mariner VI. The erring Mariner VII was ordered to switch its transmission to the omnidirectional antenna, which would be unaffected by the assumed rotation. Eleven minutes after the command went up, Mariner VII's signal appeared in the receivers on Earth. Contact would be lost and regained twice more, but the worst was over.

The good news arrived about the same time the operations team observed that Mariner VI had taken its seventeenth close-up picture of the Martian surface, about half-way through its near-encounter operations. Engineering-model versions of the pictures, and data from the three other instruments, were being received in a steady stream from the elder spacecraft. Only one hitch had developed: one of the two detectors of the infrared spectrometer was not functioning. It was designed to operate at about $-400°F$, and part of the two-stage liquid-gas-jet refrigerator had failed.

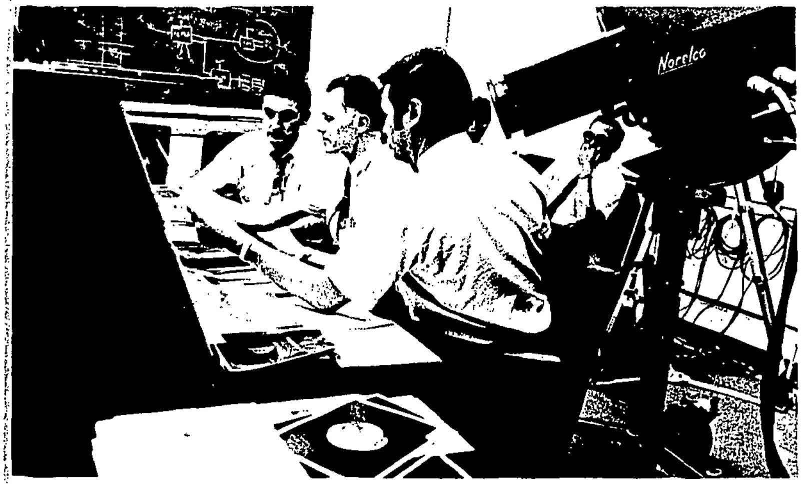
The five sensors inspected the equatorial deserts of Mars, sliding along below Meridiani Sinus and Sabaeus Sinus, from afternoon through evening, and then, with the TV cameras off, across part of the night side and into space. A few minutes later, Mariner VI slipped behind Mars, and for half an hour its signal was absent from the sensitive receivers in California and Australia. When it came back, it was already replaying the scientific data which had been sent at high speed during the encounter. The next night, when it rose over Goldstone, it would play out the 25 television pictures of the surface of Mars, and then continue the slow scientific playback. But now primary attention turned to the ailing Mariner VII.

The Unperturbed

It was reconstructed long afterwards that the storage battery on Mariner VII had failed just before the signal loss, probably through an internal electrical breakdown which built up enough pressure to burst open part of the airtight case and spray out the liquid electrolyte from one or more of the eighteen silver-zinc cells. Vaporizing in the vacuum, this created a temporary atmosphere inside Mariner, as well as condensing or freezing in various places. Some electrical terminals in the spacecraft carry very high voltages, and it is likely that lightning was added to the rain and ice. After the storm was over, Mariner VII was whirling, and many of its circuits showed temporary electrical damage. Another storm occurred several hours later, apparently, causing more damage and permanently garbling about 20 engineering measurements. Just as things were settling down after this session, a bright particle led the star tracker astray, and the spacecraft had to roll and reacquire Canopus.

One can scarcely describe as "unperturbed" a system which has sustained as much damage as Mariner VII. It was nudged very slightly off its course by the jetting effect of leakage; its central computer and sequencer and the scan-platform controller had had some of their settings upset; and there were those lost measurements. Yet the spacecraft was still heading for Mars, still communicating clearly, able to orient itself and draw electrical power from the Sun; there was no direct evidence that the scientific program had been affected. Fortunately nobody knew about the battery.

There was no shortage of theoretical cloth in which to wrap the unexpected events. There was a meteorite theory, a two-meteorite theory, and an inner asteroid belt theory (which noted that both Soviet and earlier U. S. craft had had difficulties at about the same radius from the Sun). There was a whimsical Great Galactic Ghoul theory which entertained the waiting scientists. There was a spectrometer gas bottle theory hinting at a catastrophic companion on Mariner VII of the sole and simple failure which had denied Mariner VI's infrared



spectrometer half its information. But theories were for later. Now there were things to do.

First, the spacecraft computer—the valuable but vulnerable brain of the spacecraft, second of its kind in space—had to be checked for errors in its memory and upsets in its logic. A single command produced a readout on Earth of the memory, and a simple sequence cleared the logic circuitry. The memory was unperturbed.

Second, attitude control and power had to be checked, for they would be essential supports of the Mars encounter. Telemetry and tests showed them to be functioning reasonably well, except that the telemetry channels for Canopus brightness and cone angle were unreadable—part of the damage to the telemetry system. But the spacecraft had successfully acquired Canopus after the difficulties, and it would be on gyro control at Mars.

Third, the scientific instruments had to be operable. Until they were turned on, shortly before far encounter began, three days out from Mars, there could be no certainty. There was no evidence of damage.

Fourth, the scan system, which must point the instruments, had to be checked. The engineers knew the reference values for the first pointing at Mars had been scrambled in the first storm that swept over the spacecraft circuits. The second storm had taken out three of the four essential telemetry measurements of those values, so they could not be corrected directly. Also eliminated was the telemetry from the long-range Mars sensor, so the values could not be corrected by "eyeball" either.

There is always a way for an engineer, if he is lucky and clever and stubborn enough. Mariner VII's scan platform carried two auxiliary sensors of very complicated and expensive design, known popularly as television cameras. So, on Friday night, when far encounter was due to begin, science was turned on early —all instruments working—to allow for an extended recalibration operation. The cameras began shooting pictures, and as the reference directions were gradually moved, the image of Mars edged into the monitors receiving engineering-type video, and approached the center. The engineering video has a black stripe down the center, so it proved necessary to record and play back two frames to complete the calibration. Later Mariner VII pictures of Mars showed impressive detail, cratered borders, mysterious and fascinating features. But none was so exciting as the two played back before the official start of far encounter, for they showed that in spite of near disaster, Mariner VII far encounter could and would begin.

Completion of a Triumph

One reason for the dual flight and encounter of Mariner VI and VII was the hope that some information gathered in the Mariner VI pass could be fed back to change and improve the scientific efforts of Mariner VII. This came to pass when the observers saw indications of slight atmospheric haze and the strikingly irregular border of the south polar cap in the long-range Mariner VI pictures. They requested additional television coverage of the polar regions and in the passage onto the limb of the planet. This option—an increase in near-encounter pictures from 25 to 33—bore a risk, for the tape recorders would be full before the night-side data were collected, and the real-time telemetry would be the only source of dark-side data. But the risk was acceptable; high-rate telemetry had been dramatically successful on Mariner VI, and the second spacecraft had performed impeccably in the pre-encounter high-rate test.

Thus in addition to recalibrating the scan system before far encounter, Mariner VII's crew also reprogrammed the near encounter, adding to the first two swaths across the western and southern reaches of Mars.

In the three days before it drew near Mars, Mariner VII recorded and played back 93 pictures of the approaching globe, pictures clearer than those of Mariner VI, starting further out and ending closer in — only four and a half hours before closest approach.

On Monday, night of closest approach, the TV team released a near-marathon of pictures in real time. First there were engineering-model pictures of the approaching surface, at 42-second intervals; then the playback of the previous day's recorded high-quality pictures, in which the globe of Mars grew until it overflowed the screen; and then came the engineering-type near-encounter stream.

In the scientists' room in Space Flight Operations, a cold and quiet drama had turned warm and noisy, for one instrument that had not been turned on Friday night was only now revealing its condition. The infrared spectrometer could be turned on only once, and could operate only once, for its two-channel operation depended on the expenditure of tanks of nitrogen and hydrogen. These tanks had been eyed askance ever since Mariner VII had gone off the air, as possible bombs. When the rest of the instruments had been turned on, suspicion had lessened, but still. . . . The ultra-low-temperature refrigerator or cryostat was turned on, and the instrument engineers and scientists waited to see the temperatures fall . . . or, as they had

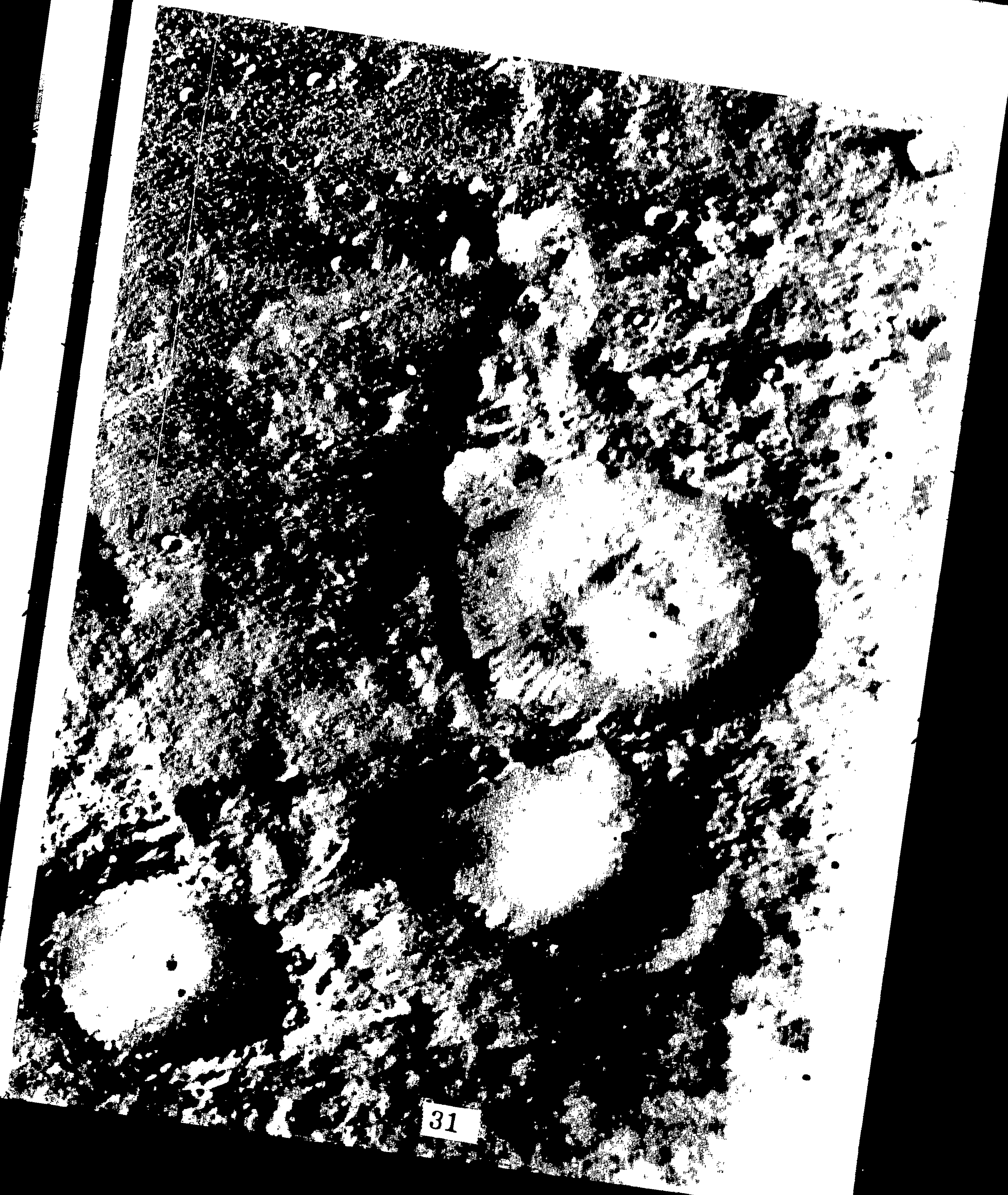
Standing by with an operating spare spacecraft on the ground, this crew backed up spacecraft encounter operations.

on Mariner VI, not fall. They waited. Finally: "it's cooling!"

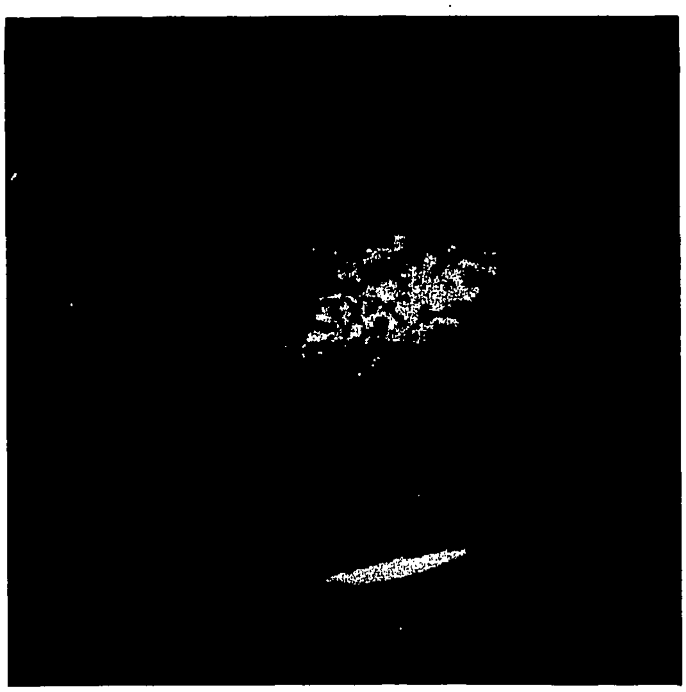
The television cameras had been taking pictures impartially, alternating their shutter-and-readout cycles every 42 seconds, for three days, whether the output was recorded or transmitted or wasted. Now at last the majestic curve of the edge of Mars appeared on the monitors, and craters and light and dark features and the south pole were visible even in the low resolution of the engineering video.

As it turned out, from there on it was clean sailing. All five of Mariner VII's instruments operated smoothly, collecting, by reason of the change in programming, more information than planned. The second occultation passage was as good as that of Mariner VI, or perhaps better in that submergence came in the region of Hellespontus, an interesting area near the earlier instrument swath.

Picture playback, the next night, was almost anticlimactic—but not quite, because of the quality and interest of the pictures. The confirming low-rate playbacks of all the scientific data, completed for both Mariner VI and Mariner VII in the weeks after Mariner VII's encounter, showed mainly that the high-rate telemetry was as accurate as it was fast—an important assurance for future missions. The low-rate playback, by the way, was only about 32 times as fast as Mariner IV's playback in 1965. After the dual encounter of 1969, the venerable Mariner IV seemed to have taken on the antiquity as well as the stature of a pioneer and trailblazer.



Letter from a Strange Land



An observer studying Mars through an unmanned fly-by spacecraft mission is, in the words of one dedicated and well-seasoned planetary scientist, a little like a veterinarian who is watching an unfamiliar species of elephant, so far away that he can barely see it with high-powered binoculars, trying to find out how the animal feels by observing the wrinkling of its skin.

Though it was difficult, as implied, the Mariner Mars 1969 scientific effort was anything but fruitless. Compared with previous efforts to observe and understand the ruddy planet, this project was expected to yield as much new information as mankind had previously possessed about Mars. The Mariner experimenters, in turn, revealed that they had gathered more data,

Facing: The great Amazonis-Arcadia-Tempe desert region of Mars viewed by Mariner VII at a distance of 282,000 miles on August 4, 1969.

Left: Closeup of the south polar cap. The Sun, slanting in from the upper left, has melted the "snow" from the northern slopes. The largest crater seen is about 49 miles across.

by and large, than they had expected, both through exercising various options to increase the scientific value of the mission and because of unexpected phenomena provided by nature.

Mars had first been described as comparable with Earth; then, after Mariner IV, it was compared with the Moon. The data of 1969 show it to resemble neither Earth nor Moon, but to have its own distinct and diverse character. It is a cold, dry, desert world of many terrain types, clothed in a thin atmosphere of carbon dioxide which condenses into polar frost and snow and into thin, high-altitude dry-ice clouds under appropriate conditions. Appearing implacably hostile to common earthly forms of life, Mars may yet be found to support its own rugged, unearthly organisms.

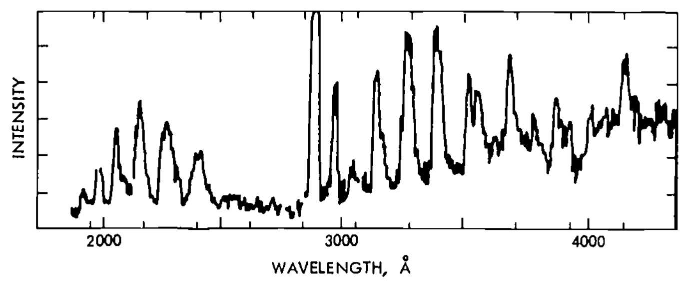
Phobos, the inner and larger of Mars' two tiny satellites, was spotted in several of the Mariner television pictures. It appears to be larger than previously estimated, and distinctly ellipsoid in shape; its position is not exactly as predicted.

The atmosphere of Mars was studied physically, chemically, and visually by the Mariner 1969 experiments. The S-band occultation experiment produced profiles of refractivity of the atmosphere at four locations, from which pressure, temperature, and other properties were derived from high altitudes down to the surface. One profile was taken near the north pole, one just north of the south polar cap, one near Meridiani Sinus close to the equator, and one in the northern desert near Nix Olympica.

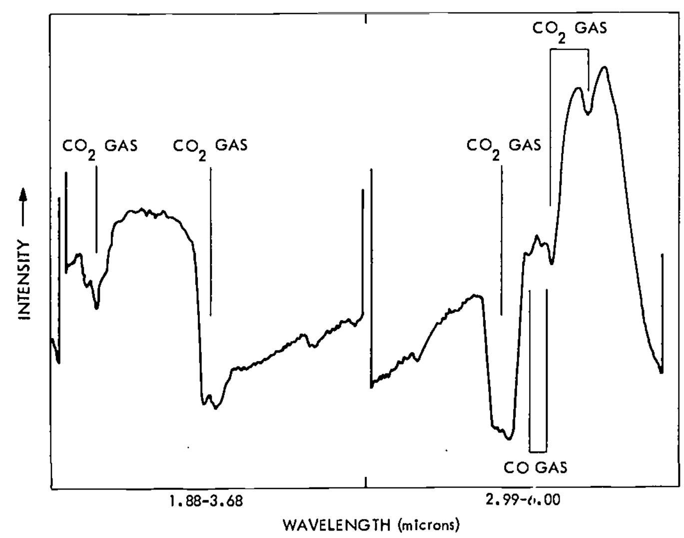
The tropical site, which was examined in mid-afternoon by local time, showed the atmosphere apparently warmer than theory would predict, out to an altitude of about 25 miles. In the other sites, the temperature profiles were compatible with theory, and over the north polar regions, it appeared that carbon dioxide could condense into clouds at virtually all altitudes. Earth-based and far-encounter Mariner pictures of Mars, showing the northern polar area hooded in cloud, match well with this observation. The ionosphere layer was detected at an altitude of about 85 miles, with a peak density of about 170,000 electrons per cubic centimeter on the day side, but no ionization was observed over the night side; these results are consistent with those obtained from Mariner IV in 1965.

Carbon dioxide and its dissociation products were found by the Mariner spectrometers to dominate the composition of Mars' atmosphere to an even greater extent than was the case on Venus. Traces of water vapor and ice, and an assumed but undetected small quantity of inert gases such as neon and argon, seem to complete the list of components of Mars' thin, cold air.

Facing: Selected wide-angle closeups of Mars laid in place on a globe. The Mariner VI pictures make two horizontal rows above, the Mariner VII data slant southward, and sweep over the south polar cap. Note that these pictures are not fully processed, and show some residual images of the edge of the planet, but the profusion of craters is obvious. Outlines show coverage of other overlapping frames.



One of 1000 pairs of ultraviolet spectra taken by the two spacecraft. This one was obtained early in the Mariner VI pass, looking tangentially at the upper atmosphere. The sharp spikes represent ultraviolet emission (glowing) by carbon dioxide and carbon monoxide in the atmosphere.



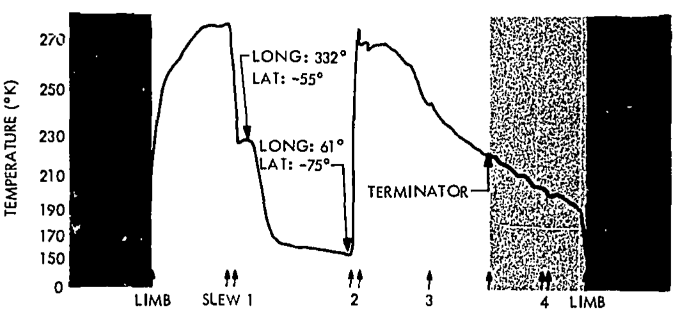
One of 180 pairs of infrared spectra taken by Mariner VII shows characteristic dips caused by absorption of heat radiation by carbon dioxide, the major constituent of Mars' atmosphere, and carbon monoxide. Other spectra revealed finely divided dry ice, and traces of water ice.

A very high, extremely thin cloud of atomic hydrogen surrounds the outer atmosphere of Mars as it does Earth and Venus. Atomic oxygen, carbon monoxide, and various ionized particles, presumably resulting from

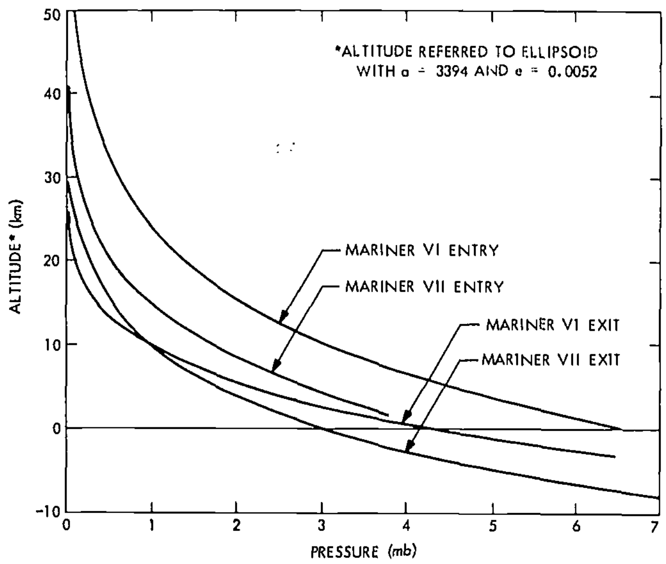
the breakdown of carbon dioxide by solar energy, were detected in the upper atmosphere. The striking features of the composition of Martian air were the absences. Nitrogen was not detected, nor were any of its gaseous compounds (nitrogen is the majority component of Earth's atmosphere, and a minority component on Venus). Ozone, an unstable form of oxygen which is formed in a layer high in Earth's atmosphere and protects the surface below from lethal ultraviolet radiation, was also absent; the ultraviolet rays appear to penetrate to the surface of Mars.

The clouds of Mars, though neither as impenetrable as those of Venus nor as dramatic as those of Earth, have a variety and character of their own. They are dry clouds composed of dry-ice crystals, ice crystals, and dust: it almost certainly never rains on Mars, though it frosts a lot and may snow. The commonest clouds are solid carbon dioxide: locally, frozen air. The northern polar hood observed by the Mariners in the Martian summer of 1969 was probably of this composition. The cloud layer observed 10–15 miles above the bright limb certainly was dry ice as were what seemed to be ground fogs just above the edge of the south polar cap. The classical "W-cloud" and other daily formations long observed in particular locations may not be clouds at all, but ice frost or fog. Spectral indications tentatively associated with dust clouds appeared at lower altitude on the limb, and chemical indications of ice crystals in cloud or frost form were seen on or near the surface. The mysterious blue haze, which usually masks the planet in blue-light photographs taken from Earth, but occasionally clears up mysteriously, wasn't there. Blue-filter pictures from both spacecraft clearly showed surface features, suggesting the Martian haze theory to be an incomplete or incorrect explanation.

The temperature of Mars' surface, measured by infrared radiation in two instruments, registered a high



Temperature trace transmitted by the infrared radiometer aboard Mariner VII shows varying temperatures along the track of the TV pictures. Water freezes at 273°K on Earth; dry ice melts at about 150°K on Mars.



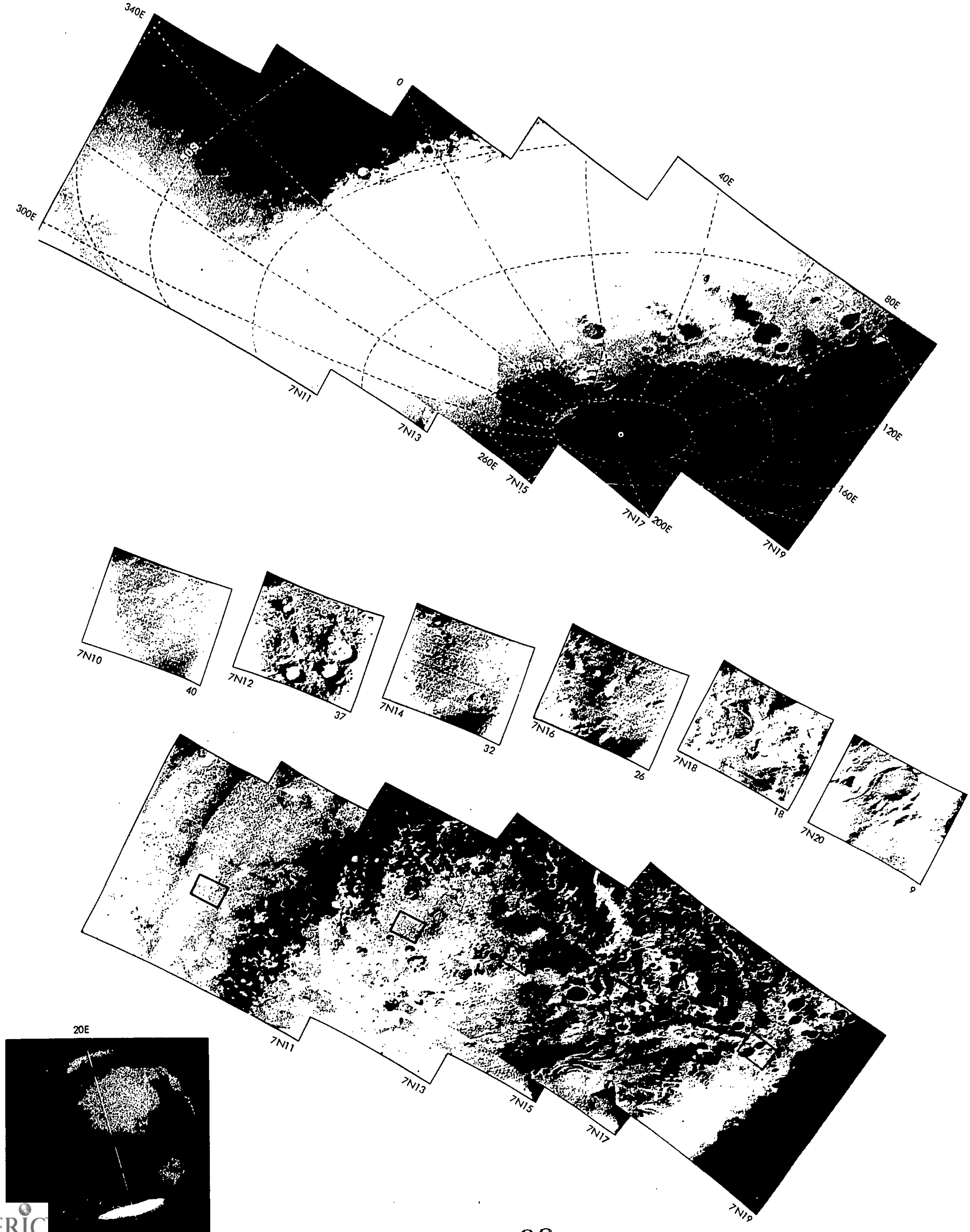
Atmospheric pressures measured at four different locations by Mariner's occultation experiment, in which each spacecraft disappeared and then reappeared from behind Mars. Mariner VI "entered" over Meridiani Sinus, an area much photographed; Mariner VII "entered" over Hellespontus, north of the edge of the polar cap. For reference, the atmospheric pressure at sea-level on Earth is about 1,000 millibars.

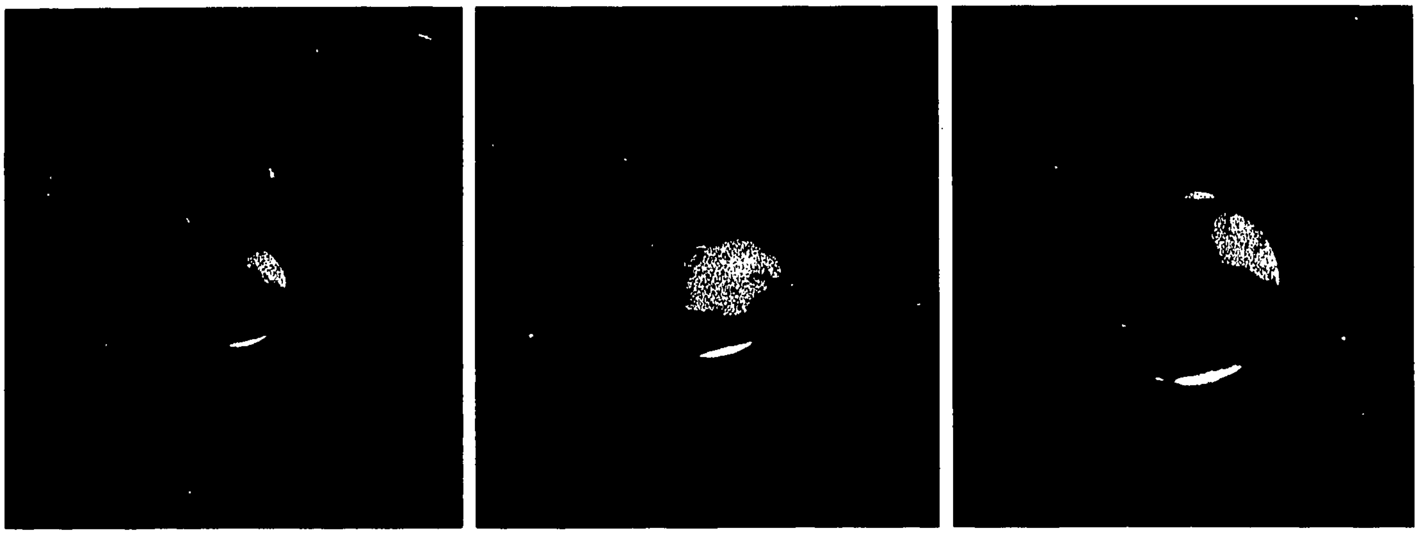
Facing: The Antarctic of Mars is shown in two versions of the same set of pictures taken by Mariner VII. The upper group is processed to show true relative brightness, so that the snowy brilliance of the cap and the gloom of the polar twilight can be seen; in addition, a geographic grid has been added to indicate the shape of the planet and the site of the pole. The lower group has been processed to highlight small crater detail, and the alternate narrow-angle pictures are added for more fine structure.

of about 60°F in the equatorial regions, on a sultry summer day, and a low of about –240°F in the dry-ice snowdrifts near the south pole. As expected, the dark regions, which absorb more solar energy in the daytime, were warmer than the light areas, which reflect more. The scientists had also expected, from the observations of Mariner IV, to find Mars covered with impact craters like the Moon, and they did.

Even among the polar snows, the circular features stood out, overlapping and interlocking. Near the rim of the polar cap, though, there was an eerie negative effect: the shaded slopes were bright, and the sunlit faces were dark. Here the cap had melted (back into the air) where the Sun struck, exposing the darker soil, while on the sheltered southern slopes the white dry frost survived.

Many classical features such as canals and sharp borders of seas do not appear in the Mariner map unless as ragged chance alignments of craters. But a new


340E
0
300E
40E
80E
120E
160E
200E
260E
80S
60S
7N11
7N13
7N15
7N17
7N19
7N10
40
7N12
37
7N14
32
7N16
26
7N18
18
7N20
9
7N11
7N13
7N15
7N17
7N19
20E



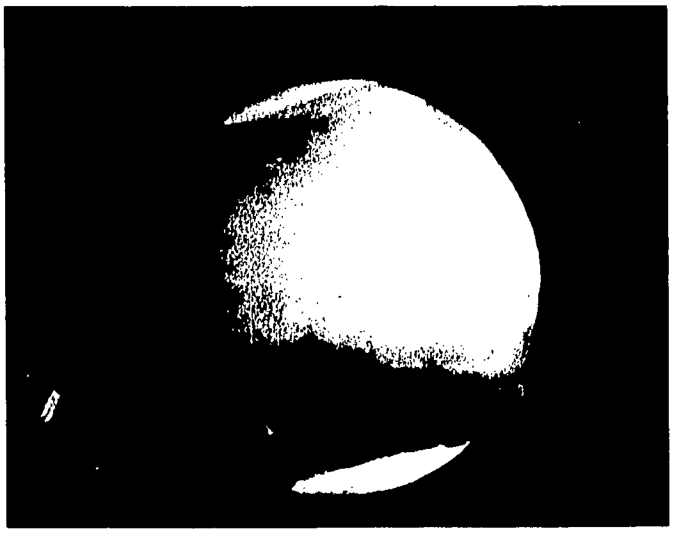
The approaching planet as it appeared to Mariner VII during the first 36 hours of far encounter. At left, Syrtis Major and Elysium are seen at a distance of 900,000 miles; in the center, after 14½ hours, the planet has rotated about 150 degrees and Amazonis, Arcadia, and Solis Lacus are visible. At right, after 9½ hours more, Syrtis Major is again visible; it is now only 525,000 miles away.

mystery appeared as Mariner VII's camera crossed into Hellas, a circular southern desert that changes from pink to white with the seasons. The western border was sculptured and terraced with familiar craters, but in the depressed floor of the feature there were first a few, and then no craters at all, for hundreds of miles. The small high-resolution pictures showed the same. The few features spotted along the edge of the floor showed that it was not a cloud layer which blanked out Hellas. What it is that has completely erased these characteristic marks of an ancient bombardment is yet to be discovered. It was as if the sea had flooded in—yet liquid water can't exist on Mars.

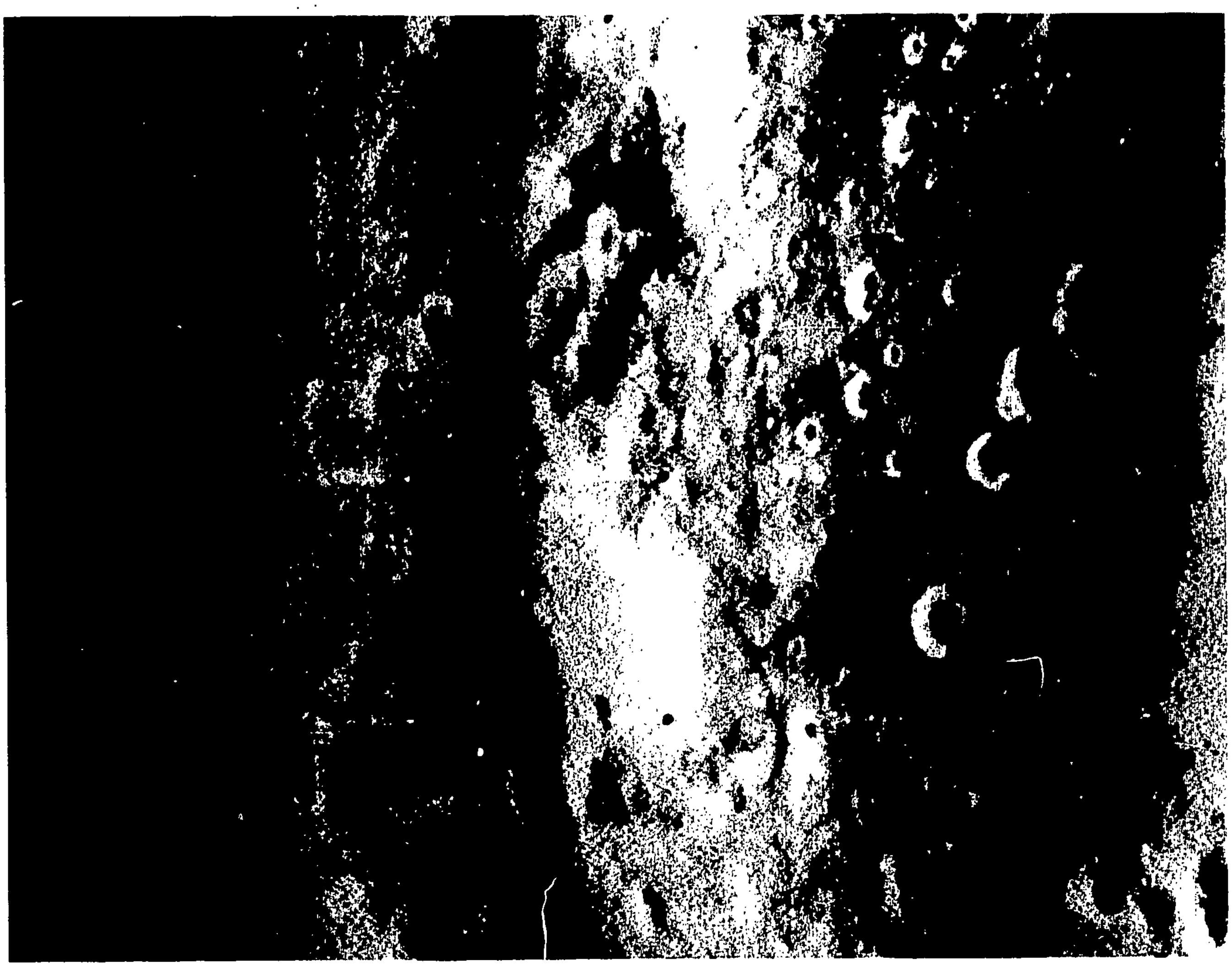
From Aurorae Sinus across the southern part of Margaritifer Sinus, along the equator, another strange land is visible; the experimenters call it chaotic terrain. In a vast network of strips and blotches, the surface appears collapsed and tumbled into a mess of short ridges and depressions that could be called the badlands of Mars. Though bordered by conventional cratered territory, these chaotic areas are not cratered themselves, suggesting that they were formed, like the featureless desert of Hellas, after the age of cratering.

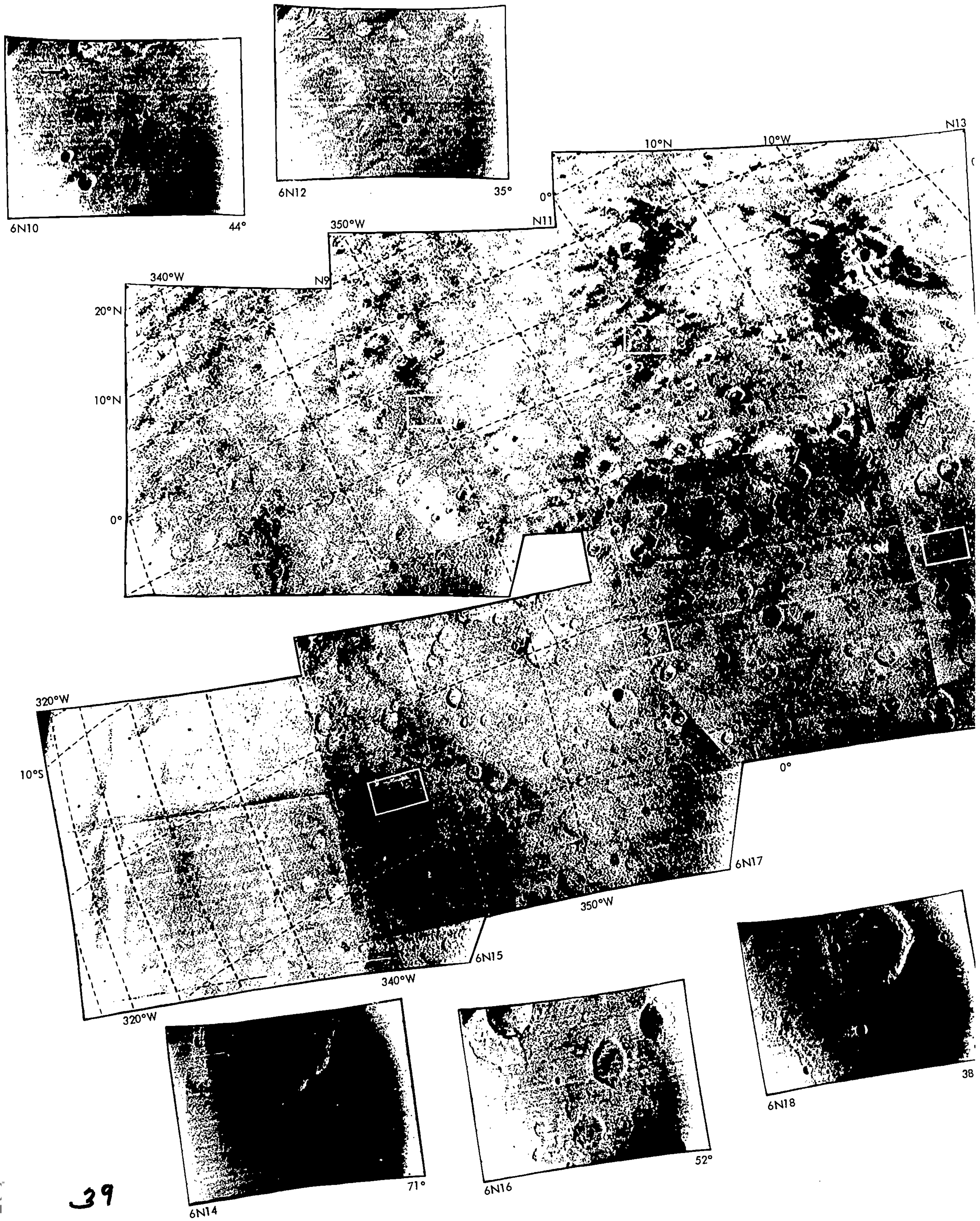
The absence of Earth-like features such as mountain chains and valleys in the Martian regions examined by Mariner VI and Mariner VII tells us that the forces which have shaped our lands have not worked upon the crust of Mars, at least in the time whose history is portrayed in its visible features. In addition to the processes resulting in the featureless and chaotic areas, many of the craters show modification. Analysis of craters by size and apparent relative age suggests that some have been weathered completely away, and that they may have been formed or modified in two or more distinct waves of activity. Like lunar craters, the Martian features may be divided into larger flat-bottomed ringwalls and smaller cup-shaped craters. Members of both groups show evidence of erosion or other modification, especially along the edge of the polar cap where the snow enhances contrast.

Insofar as the processes which shaped Earth's features are associated with the kind of atmosphere we have, it would seem that Mars never had such an atmosphere. There are two alternative theories of the origin of the atmosphere, either that it was formed at the same time as the planet, with the common light gases hydrogen and helium leaking away in the ensuing millions of years, or that it issued forth from the rocks after the planet was formed, as is believed to have happened on Earth. Either case would allow a majority of carbon dioxide, but both call for a significant minority component of nitrogen, which remains undetected on Mars. What happened to the water is almost as much a mystery for Mars as it is for Venus, although on Mars it would be likely to remain permanently frozen below the surface. The escape or removal of such permafrost in particular areas could well account for the chaotic terrain. The survival of so many craters of great age makes it clear, if these features are as old as they look, that a dense atmosphere and broad seas, with the rapid and drastic erosion they produce, never existed on Mars.



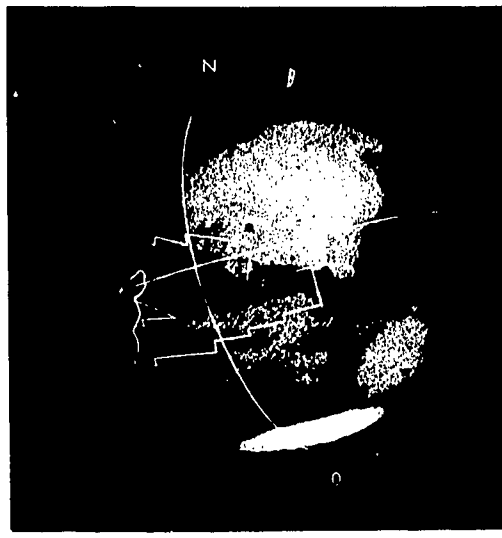
Mars continues to hurtle towards Mariner VII. Above left, 245,000 miles distant, showing the bright ring of Nix Olympica. Above right, 8½ hours later and 100,000 miles closer, the dark region called Mare Cimmerium. Below, viewed in near encounter at a distance of only 5000 miles, the cratered terrain around Meridiani Sinus stretches north (left) to the horizon.



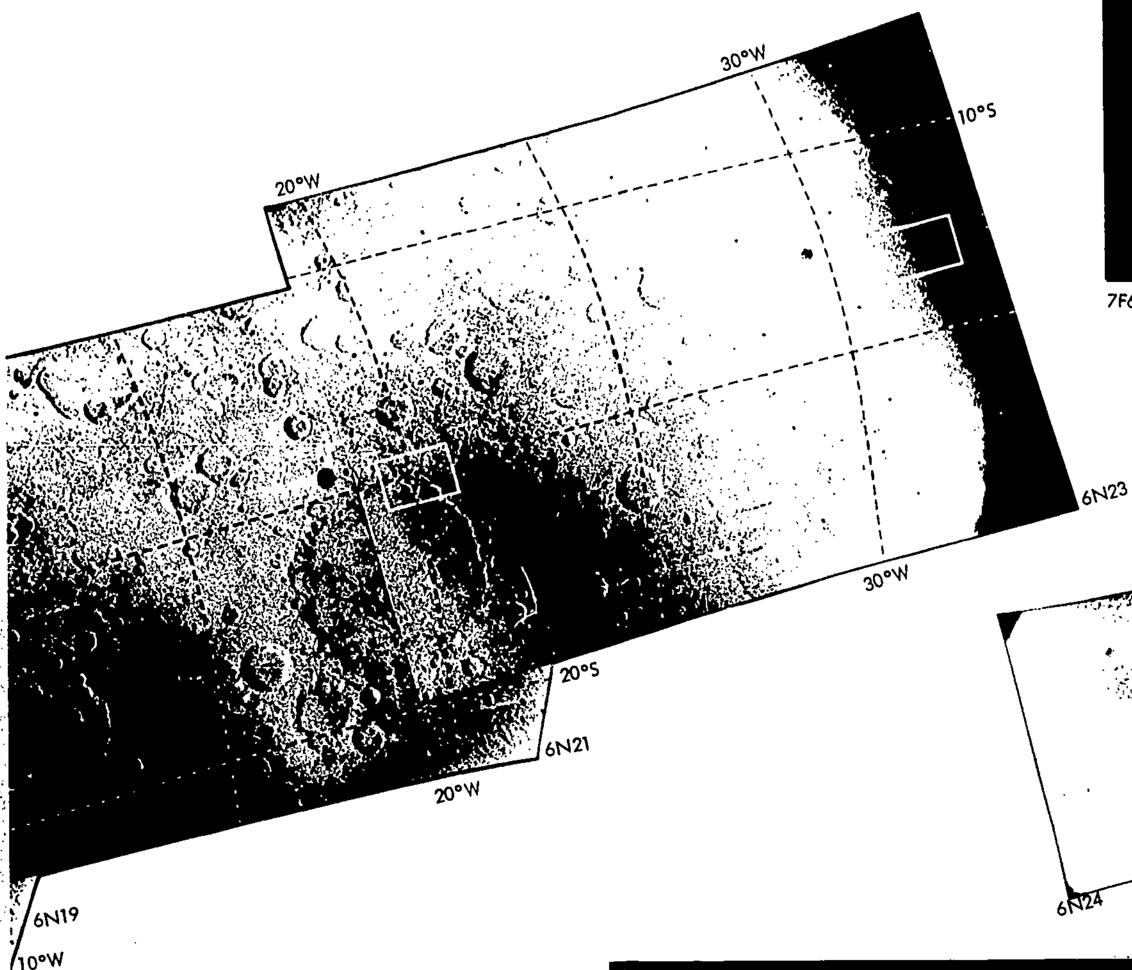


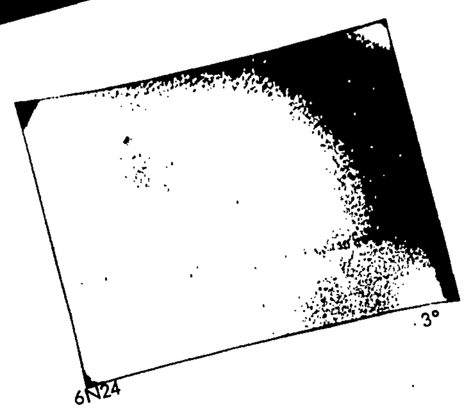
6N10
44°
6N12
35°
10°N
10°W
N13
0°
N11
350°W
340°W
N9
20°N
10°N
0°
320°W
10°S
0°
6N17
350°W
6N15
340°W
320°W
6N18
38
6N16
52°
71°
6N14

The area seen near the horizon by Mariner VII had been mapped five days before from nearly overhead by Mariner VI. This Moon-like cratered surface, seen from further away, is resolved into Meridiani Sinus and Sabaeus Sinus, with a dark/light border running from the center away to the right, about a third of the way down the row of pictures. At extreme left, the dark sky is visible in one corner; near the horizon lurks some of the mysterious chaotic terrain.

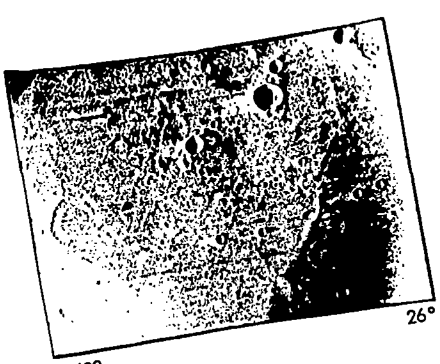


7F67

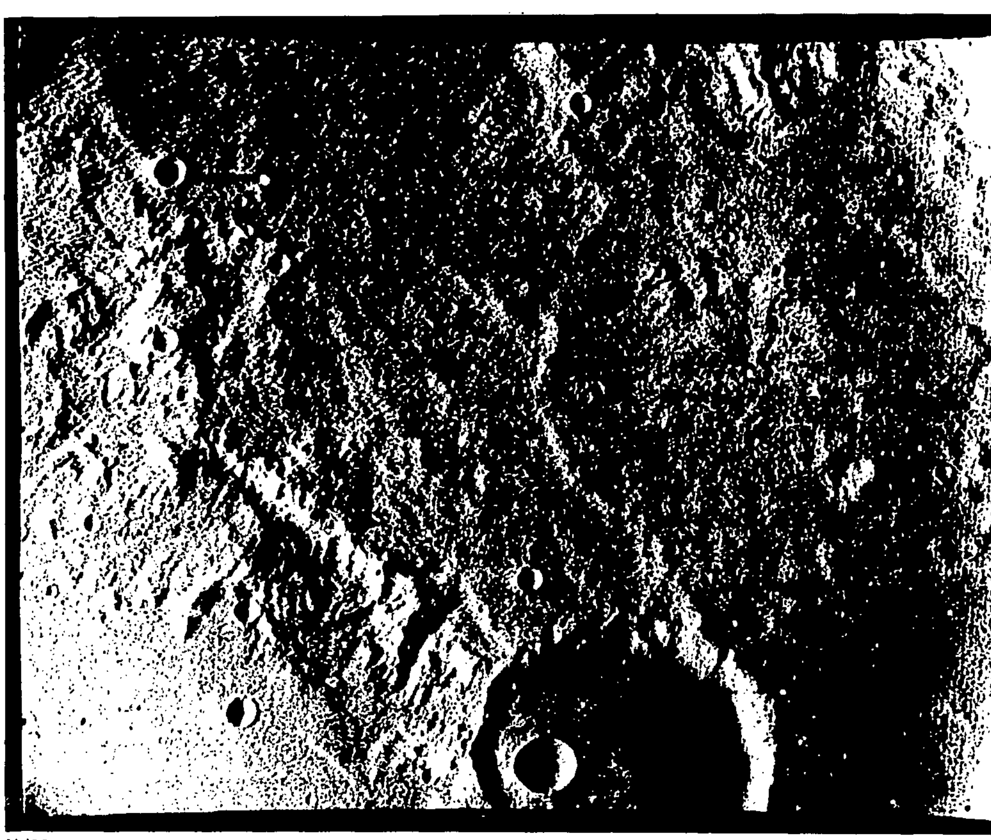




6N24



6N20



6N22

Forever Mariner

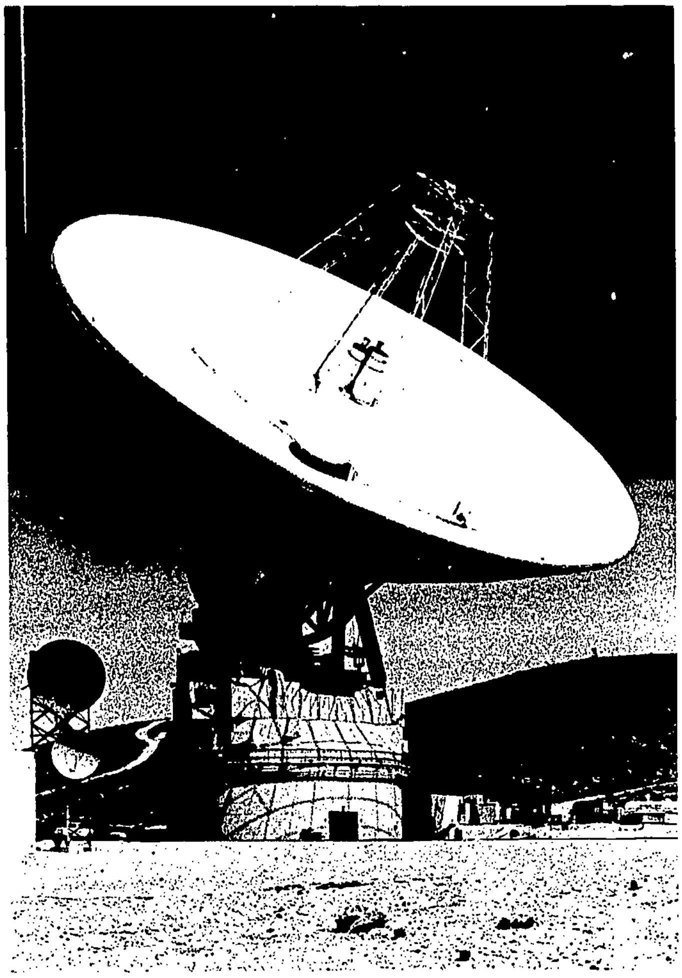
The two spacecraft coasted on beyond Mars, their solar system speed of 50,000 miles per hour relatively undiminished. It is characteristic of Mariner space probes that they do not stop once they have accomplished their missions.

Calculation of their flight paths continued, both refining the dimensions of the two Mars passes and projecting into the future the positions and motions of the craft. Engineering tests and studies focused in a similar way on understanding past performance and future capability. And the desire to probe scientific performance and possibly add some new information prompted several scans of stars and a comet in visible, infrared, and ultraviolet radiation.

Mariner VI and Mariner VII would be directly opposite the Earth in orbit (the position called superior conjunction by astronomers) in late April and early May 1970, having by that time passed the furthest point from the Sun (aphelion) and started back toward warmer regions. In September and October 1971 they would come as close as 66 to 65 million miles from Earth. The nitrogen gas used by Mariner VI to maintain its orientation was expected to last well into 1971, and Mariner VII's gas was good nearly as long. For the rest, they would operate indefinitely until some crucial part wore out, or some rare incident of space closed them down.

In the meantime, they could still be of service to science, even as bottles tossed overboard by cruising ships on Earth, containing only a note of their starting location, can help to chart the currents of the ocean.

Possibly the greatest theoretical achievement of early twentieth-century physics, Einstein's General Theory of Relativity had defied efforts to find a simple and precise experimental test. It had predicted a number of physical effects, most of which were extremely difficult to verify. One of these effects is simply gravitational, and was attacked by observing the precession of the major axis of the planet Mercury's elliptical orbit. This test is complicated by the fact that the



The Mars Station of the Deep Space Network, with 210-ft reflector, high-power transmitter, and quick-change tri-cone feed, tracks Mariner VI and Mariner VII through superior conjunction, beyond the Sun, at ranges up to 240 million miles.

Sun's precise oblateness or shape is unknown, and part or even all of the effect measured could be explained by non-relativity physics.

A second effect, measured through the "red shift" in the spectrum of a double star, had to do with time or frequency. This effect was measured in 1960, but again it was found that the underlying theory could be separated from relativity.

The third effect was the bending of light by a gravitational field. Unfortunately the effect is very small, and the gravitational field must be very large. The bending of starlight by the Sun was observed during total solar eclipses, but the uncertainty in the measurements remained fairly high—about 20%—which could confirm a relativistic effect but not measure it accurately. And by this time there was at least one modified theoretical prediction competing with the original.

The fourth effect was analogous to the bending of starlight, but paradoxically opposite in degree—at least apparently. It is called ranging delay. We tend to consider light as a stream of particles and compare these to big objects like spacecraft or meteorites, whose paths are also bent when they come near something as big as a planet or star. A spacecraft is usually speeded up in this process. But in measuring ranging delay, we observe an apparent slowing down of the round-trip radio signal. Actually there is no speeding up or slowing down, for the effect results from the distortion or stretching of the fabric of space by the intense gravitational field.

This space distortion proved to be measurable by the delay method as a byproduct of the existing Mariner VI and Mariner VII systems. An essential component of their navigation equipment was a loop of radio signal stretching from the Earth-based transmitter–receiver to the spacecraft and back. Measuring the change in the tightly controlled frequency could tell, according to the Doppler effect, the relative velocity of the spacecraft; measuring the travel time of the signal, at the speed of light, could tell the distance. The use of these measurements to determine the spacecraft's flight path (and recommend corrections) is called navigation. Their use to measure gravitational accelerations imposed on the spacecraft by various members of the Solar System, and thus to measure the position, motion, and mass of such a body as Mars, is called celestial mechanics, which was one of the Mariner experiments. The use of the ranging measurement to determine the effect of solar gravitation on the two-way radio signal itself became the relativity experiment.

The same experiment had been attempted using the planets Venus and Mercury as passive partners for the two-way loop, but they are not very good radar reflectors for this purpose, and did not provide a satisfactory return. An active partner was needed.

General relativity predicted a delay of a few thousandths of a second in the two-way signal return time of up to about 40 minutes (the one-way signal time from Mars at encounter had been only about three minutes), which corresponded to a difference in measured range of as much as 35 miles out of a total Earth-to-spacecraft distance of 250 million miles. This experiment requires an extremely precise ranging system, and a very sensitive one, since the uncertainty of range measurement must be many times smaller than the maximum difference, with received signal levels much weaker than those used before for this purpose. A number of changes were made in the Earth-based systems, which were already the most sensitive of their kind in the world, as the year-long experiment began, and the data began to roll in.

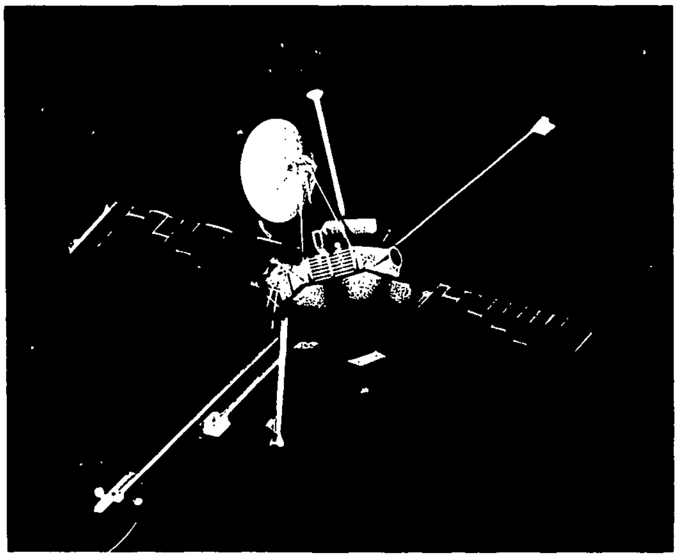
Thus the Mariner VI and Mariner VII spacecraft and the Earth-based components proved once more the adaptability which had brought to a successful conclusion a very complex planetary mission by converting in flight to a new scientific effort. In this they joined the Mariner V spacecraft, converted on the ground from a spare for the first Mars mission to the Venus machine of 1967, and the conceptual Vega spacecraft of a decade before, which was to be readily adaptable for lunar or planetary flights.

Even as the two craft left the Mars mission behind and joined earlier Mariners, the Pioneer interplanetary observers, and a host of other spacecraft as man-made planetoids in permanent solar orbit, Earth was busy making more. Two spacecraft for the Mariner Mars 1971 orbiting mission were in the shops, while participating scientists pored over the data from 1969. A 1973 Mariner flight to Venus and Mercury was being planned, with one eye on the devices and techniques used successfully in 1969. And later, larger Mars and interplanetary flights were being designed and conceived, building from the new foundation of the dual Mars fly-by.

Though it was probably the last mission of its kind, Mariner Mars 1969 turned a corner and made a new beginning. Like the rest of the interplanetary ships we will never see Mariner VI and Mariner VII again, but their cargo of scientific information has been in port since August 1969, and the results have been appearing in the marketplaces of ideas ever since.

Mariner Mars 1971 orbiting spacecraft design.

Mariner Venus/Mercury 1973 spacecraft design.



Bibliography

Mariner Mars 1969 Project (Final Report), Technical Report 32-1460, Jet Propulsion Laboratory, 3 vol., in press.

"The Surface of Mars," R. B. Leighton, *Scientific American,* Vol. 222 No. 5, pp 27-41, May 1970.

Mariner Mars 1969, A Preliminary Report, NASA SP-225, National Aeronautics and Space Administration, November 3, 1969.

"The 1969 Mariner Mission to Mars," C. E. Kohlhase, H. W. Norris, J. A. Stallkamp, and H. M. Schurmeier. *Aeronautics and Astronautics,* July 1969, pp. 80-96.

The Book of Mars, Samuel Glasstone, NASA SP-179, National Aeronautics and Space Administration, 1968.

Handbook of the Physical Properties of the Planet Mars, C. M. Michaux, NASA SP-3030, National Aeronautics and Space Administration, 1966.

Return to Venus (Mariner Venus 1967), J. H. Wilson, Technical Memorandum 33-393, Jet Propulsion Laboratory, 1968.

Report From Mars, Mariner IV, 1964–65, NASA EP-39, National Aeronautics and Space Administration, 1966.

TM 33-459 JPL 754 12-70 3M

EP-90

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION